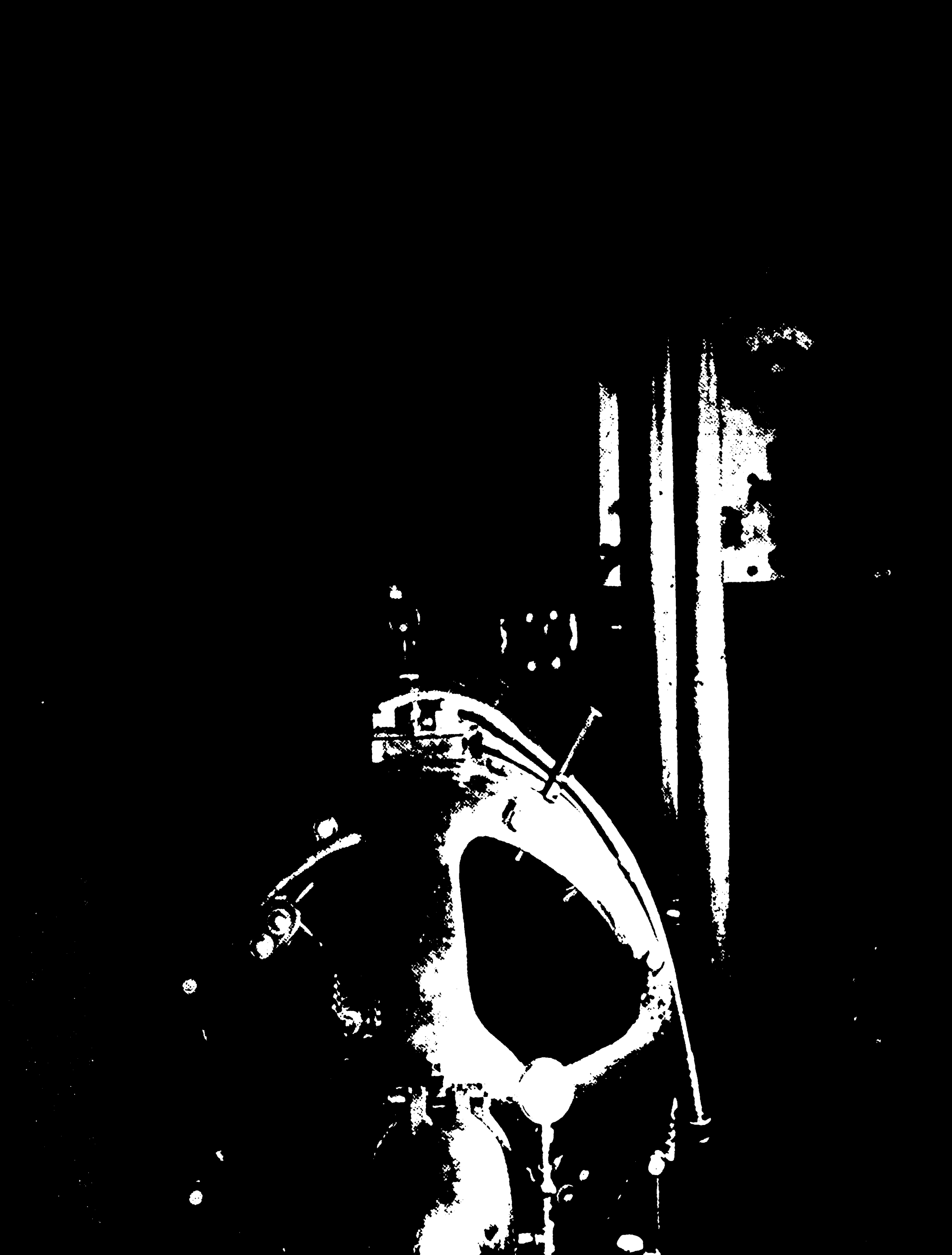

Investigation of Methods of Railway Train Lighting

Edward Wray

BULLETIN OF THE UNIVERSITY OF WISCONSIN

NO. 268

ENGINEERING SERIES, VOL. 5, NO. 1, PP. 1-142

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BY

EDWARD WRAY

A THESIS SUBMITTED FOR THE DEGREE OF ELECTRICAL ENGINEER
THE UNIVERSITY OF WISCONSIN
1906

Published bi-monthly by authority of law with the approval of the Regents of the University and entered as second-class matter at the post office at Madison, Wisconsin

MADISON, WISCONSIN
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PLATES.

FOREWORD

In presenting the report of this investigation the writer realizes that it deals with the operation of commercial apparatus manufactured and installed by private interests, and accordingly a determined effort has been made to eliminate all commercialism, presenting merely the facts as they were found in the pursuit of the tests of this apparatus.

The work has been done in connection with the college of engineering of the University of Wisconsin by parties aggregating ten engineering students with which the writer was associated. The details of these tests may be obtained from the graduating theses written by the senior students of these parties, to which due reference is made later. This report contains no minor data, in that only the typical results, as selected from the great mass of test data, are presented.

I wish to take this occasion to express my appreciation of the interest and efforts of the various railway officials under whom this series of tests has been carried out, without which it would have been impossible. I refer to Mr. C. B. Young, Mechanical Engineer, C. B. & Q. Ry., Mr. W. J. Bohan, Chief Draughtsman, Northern Pacific Ry., Mr. J. F. De Voy, Mechanical Engineer, C., M. & St. P. Ry., Mr. A. J. Farrelly, Electrical Engineer, C. & N. W. Ry.

Mr. F. W. Huels, instructor in steam engineering, University of Wisconsin, very ably conducted the tests of the Westinghouse Engine equipments on the C., M. & St. P. Ry., and the C. & N. W. Ry., and is now following this with some tests to determine the effect of reciprocating engines and turbine equipments in the baggage car, on train vibration.

I also wish to thank the senior students of the testing crews for their efforts and assistance in making these tests: I refer

to Messrs. W. A. Bertke, J. I. Bush, O. B. Cade, H. L. Heller, A. U. Hoefer, Edgar Kearney, C. S. Peters, I. L. Reynolds and A. J. Walsh.

I also wish to take this occasion to express my deepest appreciation of the able guidance and inspiration given to this investigation by my friend and teacher, D. C. Jackson, Professor of Electrical Engineering, University of Wisconsin.

EDWARD WRAY.

INVESTIGATION OF METHODS OF RAILWAY TRAIN LIGHTING

CHAPTER I

INTRODUCTION

The subject of railway car lighting is one which, like the railway itself, has developed with the times. It is a tradition that the honor of first lighting railway cars belongs to one Thos. Dixon, the driver of the *Experiment*, as the coach was called, on the Stockton & Darlington Railway, England, in 1825. It is said that on the dark winter nights, out of pure goodness of heart, he used to bring in a penny candle and set it on the rough oak board that served as a table in the center of the coach. In those days the railway companies made no effort to light their cars except to offer candles for sale to passengers. Gradually times changed and the railway companies furnished a few smoky candles to be placed in each car. This was only to enable the passenger to find his way in and out of the car and took no thought of his real comfort and accommodation. Later, oil lamps were substituted in place of the candles, and these, though at first only a slight improvement over candles, were improved and developed to give a fairly good light as the railway practice developed.

Car lighting has followed the same general lines of development as have the common methods of house and street illumination, but at no time till within the last few years has any method of railway car lighting been equal to that employed in houses or public places. The reason for this is obviously in the great difficulty of adapting any method of illumination to

the severe conditions of railway service. But, nevertheless, practically all of the house and street illuminants have been utilized in lighting railway trains and in addition to this the vast application of compressed Pintsch gas for lighting railway cars has been developed.

While a consideration of all of the various methods of car illumination would be very interesting, they cannot be considered within the limits of this investigation, so in the ensuing chapters the subject will be treated only in the application of electricity to the illumination of railway cars.

As early as 1881, the London, Brighton and South Coast Railway of England tried lighting some of their cars from electric storage battery sets, and at the same time experimented on trains with dynamos, located in the guards' van, driven from the car axle. This, by the way, was only two years after the development of the incandescent lamp.

Several experiments on other English railways followed directly; the Great Northern equipped several trains with a dynamo mounted in the guards' van driven by the car axle and furnishing light to the entire train, there being a storage battery auxiliary to light the lights while the train stopped. A little later, the Great Eastern equipped eighteen trains with a system employing a dynamo located on the tender driven by a steam engine; this receiving steam from the locomotive. On these trains an auxiliary storage battery was placed on each car.

The results of these early experiments in England seemed to favor the axle driven system as operated on the Brighton; that company being so well satisfied with the equipment as to operate about 300 cars by this method of lighting, and the company still operates about 200 cars on the same principles. These, however, are being rapidly replaced by the Stone axle equipment, described more fully later.

In France, as early as 1886, a train was equipped with a set of bi-chromate primary batteries and was operated for a year or so on cars running between Paris and Brussels. Numerous experiments were also made using lead accumulators to light the cars, but these, due to the imperfect and expensive lead accumulators of that day, were quite inconclusive and unsatisfactory.

Later, however, as the lead cell was perfected and cheapened in price, this type of equipment came into more general use in France.

In Germany the use of storage batteries was developed at an early date to such an extent that by 1893 about 2,500 mail cars alone were equipped with this form of illumination.

In 1898 the Prussian State Railways conducted a series of tests on the Stone axle equipment (see page 12) but after about two years' trial of these equipments they were abandoned and all apparatus was removed from the cars.

Later, in 1900, the Prussian State Railways began experimenting with steam driven generators, and as a result of these experiments have adopted as standard equipment, a system using a steam turbine generator set located on top of the locomotive that operates at full boiler pressure and is controlled by the engine driver. There is also an auxiliary of storage batteries on the cars for use during engine changes. This equipment is very satisfactory and its operators believe they have at last found a solution of the train lighting problem.

Developments in America did not receive such a stimulus in the early days. In 1886 the Boston and Albany Railway equipped a few cars with straight storage battery equipments as an experiment, but found it rather expensive as shown by the statement of Mr. F. D. Adams, their Master Car Builder, in 1892 when he said "no road can afford to put electric lights on its trains; any road of modest dimensions would be ruined by it in a little while." In the year 1885 the Pennsylvania Railroad Company equipped eight of its parlor cars with storage cells for lighting purposes. The next year witnessed an active campaign by the two battery companies then in existence and several cars were equipped with this type of equipment and to this day the Pennsylvania road has a large percentage of cars equipped with straight storage battery lighting.

The Chicago, Milwaukee and St. Paul Railroad has been particularly active in the development of the steam driven generator sets, more commonly known as "baggage car" or "head-end" sets. As early as 1888 this road equipped a special car with a boiler and engine-generator set, the purpose of which

was to furnish both light and heat to the whole train during the winter months. In the summer the engine and dynamo were transferred to a baggage car where they operated to light the train. This equipment was successful in its operation and gave some gratifying results in regard to cost of operation. These are discussed more in detail in another part of the report and will not be considered further here. Sufficient to say that that road has adopted the high speed Westinghouse engine-generator set located in the baggage car, as standard equipment, and is at present using essentially the same equipment, having about 300 cars equipped for this kind of lighting.

Recently the General Electric Company has developed a Curtis turbo-generator set for this service operating at 3,600 R. P. M., which is also discussed at length later and will only be mentioned here.

The De Laval Turbine Company have several turbo-generator sets in operation on the Pennsylvania Railroad for lighting its through trains. These are located in the baggage cars and operate at 20,000 R. P. M., a 10 to 1 gear transmission driving the generator at 2,000 R. P. M.

The Pennsylvania Railroad Company has also recently equipped several of its engines with Curtis turbine generator sets located on top of the locomotive such as the Germans have found so satisfactory.

The development of the more modern methods of axle lighting has been worked out largely in America, and some of the more typical devices will now be described. The axle lighting problem is, however, discussed more comprehensively on page 111.

Development of Axle Lighting in England

The earliest attempt at lighting a train by means of a generator driven from the axle was probably that made in 1883 by the London, Brighton and South Coast Railway in England. A generator was mounted in the guard's van and was belted to the axle. A mechanical device served both as pole changer and automatic switch. This consisted of a large threaded screw or worm fitted into a half cylinder laid horizontally. Mercury was then

poured in and the worm belted to the generator. As the speed increased the mercury was forced to an end of the cylinder and completed the field circuit of the generator. There were two pairs of armature brushes, one pair only operating at once. These were mounted on a rocker frame which, when the circuit was closed in one tube, was caused to swing over by an electro-magnet so as to engage the proper brushes with the revolving armature. On reverse direction the mercury was forced into the other end of the tube by the revolving screw and the other pair of brushes made to operate, thus keeping the proper polarity in the circuit. No provision is mentioned for regulating voltage, the battery being depended on as a regulator. When the lights were on and the generator furnished too much current the battery took the excess and when not furnishing enough the battery made up the deficiency. When the speed of the train slackened the fall of mercury in the tube broke the circuit.

This equipment seemed to give satisfactory results, which is surprising in that no attempt was made at voltage regulation, but this is undoubtedly explained by the fact that they used a large battery, 500 ampere hour, with a 56 ampere 40 volt machine, so that on the higher speeds the increased battery charge would cause greater armature reactions, which were undoubtedly high in that machine, and would so tend to regulate the voltage inherently. This in the present stage of development would be considered as deplorably poor and unsatisfactory, though in the early days it satisfied the operators.

Later, on this same line, a modification of the above was employed in that regulation of the generator voltage was attempted by shifting the position of the brushes as the train speed increased, thus decreasing the effective coils in the armature winding. This was effected by means of a centrifugal governor which also served to close the generator circuit when the critical speed was reached. In this equipment which was very extensively employed on that road at the time, the generator and regulator were located on the guard's van and supplied light to the whole train of ten cars.

Later, in about 1896, a system known as the Stone system was developed and will now be considered.

The Stone System of Axle Lighting

This equipment was invented in 1895 by Mr. A. B. Gill, and was developed and improved by Messrs. J. Stone & Co., of Deptford, England, hence is known as the Stone system. It has reached almost universal adoption on the English railways and accordingly a consideration of the equipment must be accorded in this investigation.

The characteristic feature of the equipment is that each car is a unit by itself, thus affording a much more flexible system than that of the earlier systems of England, where the generator was located in the guard's van, this being suitable for block trains only. The equipment consists essentially of a generator, a storage battery to act as auxiliary when the generator is inoperative, and an automatic switch to close the generator circuit when the critical speed has been attained.

The principle underlying the operation of this equipment is that regulation is obtained by allowing the belt to slip. As the speed of the train rises the generator voltage will tend to rise proportionally, this causing a great battery charging current to flow, thus increasing the generator output and belt pull.

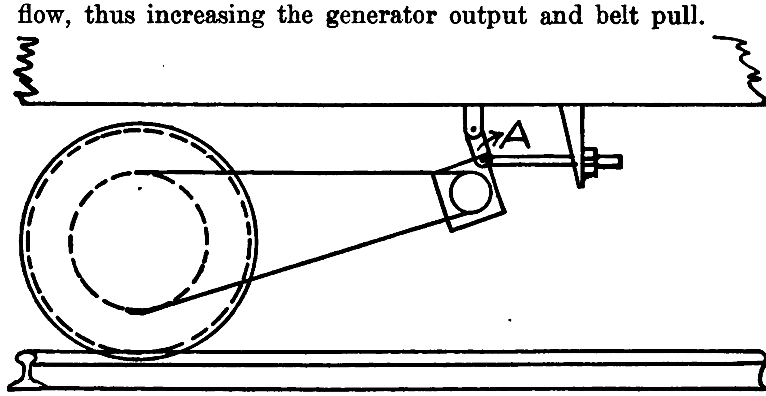

Plate I.—Showing Plan of Generator Suspension.

The generator suspension is shown on Plate I. It is supported at one corner of its frame by the adjustable link A, in such a manner that it is free to swing toward or away from the driving axle. The suspending link is so placed

that the belt draws the dynamo out of the diagonal position in which it would naturally hang, thus putting a definite tension on the belt, just sufficient to absorb the power required. It is obvious that when the pull on the belt exceeds that due to the offset suspension of the dynamo that the dynamo will be drawn toward the axle and the belt allowed to slip. Thus the generator will run at practically constant speed for all values of train speed above the critical value.

A strong mechanical governor automatically closes the generator circuit when critical speed has been reached.

A storage battery is suspended underneath the car to act as auxiliary in lighting the lights when the generator is inoperative. Another function of the storage battery is that it acts as a ballast or regulator to keep the lights constant, absorbing all the variations of generator output.

The lubrication of the generator is effected by means of an electrically controlled oil supply so adjusted that when the generator is operative oil will flow from the oil tank, but when the generator is inoperative the supply is cut off and no waste takes place.

The operation of this equipment is shown by the accompanying data of a reported test made in the presence of Professor Slaby, director of the Berlin Royal Technical College, and Professors Hagen and Neesen of the German Patent Office.

Train speed.	Speed of Dynamo.	Equivalent speed if no slipping had occurred.	Output Amperes.	Reference.
12	500	500	0	Ry. Gaz., 1898, 668.
16	690	690	2	
18	750	750	6	
20	840	840	14	
22	885	925	17	
24	915	1,025	20	
27	915	1,125	20	
30	915	1,250	20	
45	915	1,875	20	
48	915	2,000	20	
54	915	2,250	20	
60	915	2,500	20	
72	915	3,000	20	

The pre-determined speed of dynamo was 915, at which it should deliver 20 amperes. It should be noted that this was not exceeded.

In regard to the power absorbed, a test made by Professor Capper of Kings College, London, is quoted. For ordinary coaches when running at normal speeds it was found to require 0.6 H. P. to drive the generator while lighting the lights. For speeds of the express train the power absorbed does not exceed 1.1 H. P. No data are given in regard to K. W. output of generator nor exact values of speed.

The extensive use of this equipment in England is shown by the fact that by 1902 the London and Northwestern Railway had 4,000 carriages equipped with this system of lighting; also the London, Brighton and South Coast Railway had, in 1902, 293 coaches equipped with this same system. At present, in 1906, the Great Central has 330 coaches equipped, according to information given to the writer by Mr. N. Clow, Assistant Superintendent of the Line, Great Central Railway, England.

Further in regard to lamp regulation this official reported that when properly regulated, the rise and fall of voltage is not perceptible. An idea of voltage regulation may also be gained from the fact that he reports that during a period of four months operation only five lamps were burned out. This would indicate that the lamp voltage at least did not rise much above normal, but is no criterion for the lower limit which is really the important one.

In discussion of this equipment it may be said that it has the advantage of extreme simplicity and cheapness of construction in comparison with some of our later American devices. However, from a standpoint of reliability and regulation, the advantage would seem to be with the more modern American devices. The test quoted is one made in a laboratory under ideal conditions and is not typical of operations under varying weather conditions of ice and snow and rain in addition to the collection of cinders, dust and stones from the track at high speeds, while the tests quoted later of some of the American devices were made while in actual operation on the trains under unfavorable weather conditions.

Another English road having 4,000 cars equipped with this system reports that: "The light is good and steady whether

standing or running and no difficulty has been experienced during winter from frost or snow."

This type of equipment has been used more or less extensively in this country under the name of the Gould system. It was, however, quickly displaced by the more modern equipments employing electrical means of regulation, which would seem to indicate that, from the American standpoint at least, the Stone system is inferior to some of the more modern equipments.

In regard to the power absorbed, attention must be called to the fact that at normal speeds it requires 0.6 H. P. to light the car, but for express speeds it requires 1.1 H. P. to furnish lights, as per test quoted above.

This would indicate a tremendous belt loss at the higher speeds which is just as would be expected. If all the slip takes place on the armature pulley, which undoubtedly is approximately true, the power required to drive the generator would vary directly as the train speed, for, the tension of the belt being assumed constant, the power delivered by the axle would be directly proportional to the product of this tension and axle speed. This is certainly a disadvantage of the system in that it causes a useless drag on the locomotive at high speeds and will also result in the rapid destruction of belts.

CHAPTER II

DESCRIPTION AND DISCUSSION OF SEVERAL METHODS OF LIGHTING RAILWAY CARS FROM THE CAR AXLE

Moskowitz System

Of the earlier American devices for axle lighting, one of those developed by Morris Moskowitz in 1895, is most worthy of note. Mr. Moskowitz has been especially active in the development of axle devices, having developed numerous types, this one being one of his earliest. It consisted essentially of a generator with its driving gear, two sets of storage batteries, a switchboard and lamp circuit in the car and an automatic switch to close the generator circuit.

The generator was bi-polar, 45 volts, with specially designed armature winding, and having a differential winding on the fields so that it would inherently regulate for almost constant output independent of the speed of the train. The generator was driven from the axle by means of a countershaft to which both generator and axle were belted, the idea in this being to protect the dynamo from vibrations of the car axle.

Another feature characteristic in this equipment was that it employed two storage batteries, one of which was charged while the other was being discharged in lighting the lamps. A twelve point switch was supplied which controlled the circuits of both batteries and generator and was operated by the trainmen in changing batteries when one battery had become exhausted.

The automatic switch was operated by a small solenoid shunted directly across the armature terminals so that it would close the generator circuit when it attained a voltage equal to that of the

batteries, and opened the same when it fell below that of the batteries.

Electro-magnets were also employed to maintain proper polarity of the generator circuit.

The regulation as above mentioned was inherent in the generator itself, there being no other devices for regulating voltage.

In discussing this equipment it must be observed that it was not sufficiently adjustable for successful operation, the generator having a certain rated output irrespective of the light consumption. This is sure to cause very unsatisfactory operation of the batteries in connection with the equipment. From an operating standpoint the system would give satisfactory results if the generator was of sufficiently high output, in that the lamp regulation would be very good and the equipment fairly reliable. However, continued experience has shown the evils of a non-adjustable equipment and this apparatus is ready to be placed among the historical relics.

Axle Device of American Railway Electric Light Co.

This system was developed about 1896 and put into operation first on a trial car on the Pennsylvania Railway. It consisted essentially of a generator under the car, a regulator to operate field resistance, an automatic switch and a storage battery.

The dynamo was mounted inside the truck frame and geared direct to a large driving gear which was bolted to a split sleeve mounted on the middle axle of the six-wheel truck. The armature shaft was mounted in spring supported bearings to absorb shocks, etc., and was protected by dust-proof casings.

The regulator was the characteristic part of this equipment and was based on the principle of field rheostat control to compensate for variations of the generator speed. This was accomplished by means of a solenoid of heavy wire in series with the generator circuit, the magnetic flux in this coil being directly proportional to the generator current flowing. This coil would actuate an iron plunger, the motion of which would control the

resistance in circuit with the field, thus raising or lowering the voltage as was necessary to restore normal conditions.

It was said that "the charging current is made to correspond with the number of lights in use so that there is no danger of short circuiting the battery." No explanation of this could be obtained, but it was presumably affected by a differential winding on the regulator coil.

The automatic switch consisted essentially of an electro-magnet mounted on a movable arm, such that when the generator pressure reached the proper value the magnetism set up in the electro-magnet, which was connected directly across the terminals of the generator, would close the generator circuit.

The proper polarity in the generator circuit was maintained by having two sets of brushes, one of which was operative in going in one direction and the other when the direction of the train motion was reversed.

This equipment apparently has the distinction of being the first to employ the principle of field rheostat control of generator voltage, which principle was later developed and improved and now forms the basis of operation of numerous modern axle devices such as that of the Consolidated Axle Car Heating Company, the Newbold Equipment built by the Adams & Westlake Co., the McElroy system, the new Moskowitz equipment, the Henry axle system, the Deutsch system, in this country, and the Dick Vicarina and Auvert in Europe.

McElroy System

MANUFACTURED BY THE CONSOLIDATED CAR HEATING CO. OF ALBANY, N. Y.

This is an equipment which has been recently developed and has not yet come into prom~~inence~~, but has some points in its construction ~~which~~ are well worthy of consideration.

The generator is mounted directly on the trucks and is driven by a gear and pinion similar to those used on the motors of trolley cars; these being enclosed in a wrought iron gear case which is made dust-proof with leather packing.

Within the dynamo compartment is a mechanical device that determines the polarity of the circuit on reversal of the direction of motion of the car.

A battery auxiliary is supplied as in all other axle devices. This equipment is one of the type that controls by varying field resistance. The regulator is the characteristic part of the equipment and consists essentially of a compound solenoid controlling a motor, which in turn operates a field rheostat.

The compound solenoid is a part of the equipment that deserves special consideration. It consists essentially of a series coil of heavy wire placed in the battery circuit, and in addition to this a shunt coil which is connected directly across the generator terminals. Thus the control is one combined for voltage and current regulation and appears at least partially to eliminate the evils of the control by constant current.

By a proper adjustment of the ratio of ampere turns of the shunt coil to those of the series coil, the regulator may be made to protect the batteries from the destructive overcharge which is so often experienced when a constant current regulator is employed.

This, from a battery standpoint, is a very commendable improvement over the principle of control by constant current regulation and deserves special emphasis.

In explanation of the operation of this solenoid, let us assume actual operating conditions; there being 16 cells in the storage battery, the generator voltage then varies between 32 and 42 volts at different points of the battery charge. Accordingly the magnetic flux in the solenoid due to the shunt coil would vary proportionally to this pressure. This might be expressed as a variation from 320 to 420 ampere turns. Assuming that the series coil had been adjusted so that normal charging current would develop 110 ampere turns, this making a total number of 320 plus 110 equals 430 ampere turns in the solenoid when charge was first commenced. Now as the batteries become charged the voltage rises and the shunt coil magnetism is increased, thus requiring less magnetic pull from the series coil to regulate. It should be noted that the magnetic pull which balances the pull of the adjustable regulator spring is the sum of

the magnetic pull due to the shunt coil combined with that due to the battery current flowing through the series coil, and that as the one increases the other must decrease to maintain equilibrium. When charged condition is obtained, the 430 ampere turns total in the solenoid would consist of 420 ampere turns due to the shunt coil, and only 10 ampere turns due to the series coil, thus the charging current has been reduced to only 9% of its normal maximum value. It is obvious that by a suitable proportion of ampere turns due to the series and shunt coils the battery overcharge may be reduced to any desired value.

In regard to the detail operation of the controlling apparatus, the compound solenoid moves an iron plunger back and forth, which in turn makes contact through the armature of a small motor, causing it to rotate backward or forward, cutting in or out a field rheostat as may be required to regulate the generator voltage. A lamp resistance is also inserted in each lamp circuit by this motor when the generator becomes operative. The motor serves also to close the generator circuit when the critical speed is attained, thus an automatic switch is not required.

In this regulator the motor runs only when regulation is necessary, so that a minimum wear on moving parts is obtained.

In discussion of the equipment it must be said that it appears to be reliable and entirely automatic. From a standpoint of battery operation it is an admirable equipment and will likely give a much longer life to the batteries than numerous other axle devices.

In regard to lamp regulation, however, the equipment is a very poor one. It is impossible to build a magnetic solenoid to operate between an upper and a lower limit without allowing a probable error of 5 or 10 per cent. In a "current regulator" this variation of current is readily absorbed by the battery without causing an appreciable variation of lamp voltage, but in a "voltage regulator" this 5 or 10 per cent. variation is received entirely by the lamps. It is true, a certain definite lamp resistance is inserted each time the generator becomes operative,—this to compensate for the difference between voltages of battery discharge and charge, but no definite lamp regulation is attempted. Due to the series coil of the regulator being placed

in the battery circuit, the batteries will be charged entirely irrespective of whether or not the lamps are lit, so that though the lamp resistance be in circuit the rise in charging voltage of the battery will cause a proportionate rise in voltage at the lamps.

This could be largely eliminated by a slight modification of the regulator solenoid, if another series coil were added to the solenoid and this placed in the lamp circuit so that when the lamps are turned on the current through this coil will create a magnetic flux which will largely replace that of the battery charging current.

This would cause a large decrease in the battery current when all the lamps are turned on, and would accordingly require that the charging be done largely during the day. This in many cases would be a serious disadvantage, but when installed on a car making at least a part of its run during the day, it might be made to operate satisfactorily.

The United States Axle Equipment

This equipment is one recently invented by Mr. Morris Moskowitz, who has for years been associated with the development of various types of axle lighting devices, one of which has been described on page 16.

The equipment consists essentially of a generator, pole changer, storage battery auxiliary, regulator, automatic switch, and lamp circuits within the car.

The *generator* is of a four pole, shunt wound, type, encased in a dust and water-proof steel casing, provided with proper hand holes for inspection. It is driven by a belt from a large axle pulley and is suspended from a shaft which is supported by a heavy iron framework from the forward truck sill. This shaft is mounted on springs to relieve the generator of the truck vibration.

A *pole changer* is fitted to the end of the generator shaft to provide proper polarity irrespective of direction of car motion. This is effected by a dog fitted into a transverse slot on the armature shaft which throws a reversing switch; the range of action of this dog being limited to 90 degrees by means of a

steel guide. For speeds above four miles per hour this dog becomes inoperative, being drawn back into the slot by the centrifugal action of a heavier portion of itself on the opposite side of the center of rotation, thus eliminating excessive wear.

The *regulator* is a characteristic part of this equipment and is of the type which maintains constant generator current. The

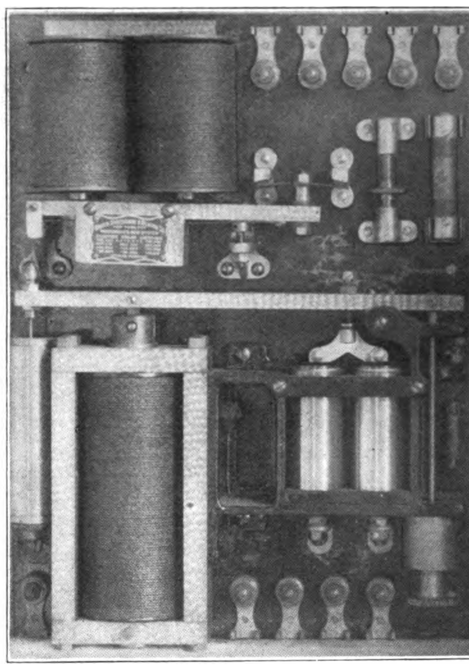

PLATE II.—REGULATOR OF THE AXLE EQUIPMENT OF THE U. S. LIGHT AND HEAT CO.

principle upon which it is based is that of a solenoid in series with the generator armature controlling the variable resistance of a pile of carbon discs in ~~multiple with~~ the generator field, so ~~as to~~ decrease the generator field current to compensate for rise in train speed, and *vice versa*. The magnetic pull of the solenoid is balanced by the adjustable pull of a spring.

This is a very simple and apparently reliable regulator in that no movements of the parts are required except the slight motion

of the floating plunger in the solenoid, necessary to produce the proper pressure upon the pile of carbon discs.

In that the field current is controlled by variable resistance in multiple with it, there is an external resistance added in the combined circuit so that the total current through the field and carbon discs together is maintained practically constant.

In order to provide lamp regulation, a lamp resistance is inserted by the regulator when regulation first begins. This is again automatically short circuited when the generator is cut out.

The *automatic switch* is similar in principle to that described on page 18, but is of radically different construction in that instead of having four little solenoids—two stationary and two movable, it consists of two large compound stationary solenoids of very robust construction, shown at the top of the accompanying figure.

In discussion of this equipment it may be said that it has the advantage of simplicity in providing proper regulation and will do so quickly and accurately. This is a very important feature in such an equipment and should be given special emphasis.

But, on the other hand, the equipment inherently contains all of the imperfections common to constant current regulators, as discussed on pages 111 to 120.

This type of lamp voltage regulation, while it cares for the variations of battery voltage from the conditions of discharging while train is stopped to that necessary to produce a slight charging current while running, it does in no way care for the variation of battery voltage due to the condition of battery charge, as considered more fully on page 125, nor is the regulation independent of the number of lamps in use.

The generator is of rather small construction in comparison with generators used in this work.

The pole changer may be said to be of excellent construction in that it is extremely simple and has no parts of excessive wear.

Everett Regulator

This type of regulator was recently devised by Mr. S. W. Everett of the Santa Fé Railway. It was designed particularly for

the purpose of obtaining more satisfactory service with an older type of axle equipment which that railway has been operating for some time.

It consists essentially of two variable shunts placed in parallel with a field rheostat, Plate III.

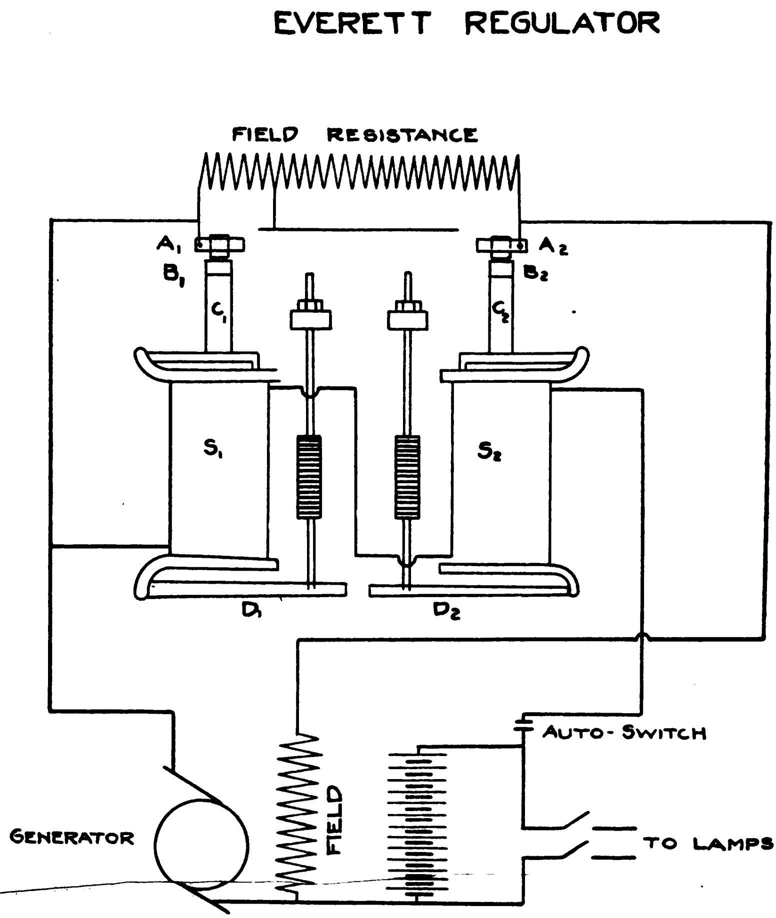

PLATE III.—SHOWING DESIGN OF EVERETT REGULATOR.

These variable shunts consist of carbon buttons, A_1, B_1, and A_2, B_2, which are operated directly by the floating plungers C_1 and C_2 in the solenoids S_1 and S_2.

The operation of the regulator is as follows: when the car is at rest the contact buttons will be held firmly together by the springs T_1 and T_2, these causing a minimum resistance in the generator field circuit. When the speed increases so that the automatic switch closes, the generator current flowing through the coils S_1 and S_2 creates a magnetic pull on the plungers C_1 and C_2, thus lessening the pressure on the carbon buttons A_1 B_1 and A_2 B_2 and increasing the total resistance in the field circuit which causes a corresponding decrease in the generator field current which is necessary to compensate for rise in train speed.

The tension on the springs T_1 and T_2 is so adjusted that the contact A_1 B_1 is first operated, then as the train speed goes still higher, that contact being open, the control is effected by the varying resistance of the contact A_2 B_2.

The regulator has many of the advantages of simplicity found in the previous equipment described, and is reported to be giving satisfactory service on the few cars on which it is installed. It has, however, all of the inherent disadvantages of the constant current regulator as described more fully on page 111.

THE DEUTSCH SYSTEM OF AXLE LIGHTING

This equipment was recently invented by Mr. I. Deutsch. It operates on the principle of constant current control by means of a large solenoid placed in the generator circuit which controls the operation of a field rheostat to compensate for variation in train speed. In the manner in which the rheostat is operated this equipment is a radical departure from the others described, in that it is operated by the air pressure from the brake pipes on the train, the supply of which to the rheostat operating mechanism is governed by the controlling solenoid.

The generator is located beneath the car but is not mounted directly on the car truck as is the common American practice, it being in this case fastened to the under beams of the car body. The generator is driven from the axle by means of a bevel gear transmission, there being a universal joint and telescopic shaft supplied to compensate for the motion of the truck on rounding curves.

There is apparently no special lamp regulation attempted other than that of controlling the generator current to a constant value.

An automatic switch, so essential in this type of equipment, closes the generator circuit when the proper voltage is attained, and opens it again when the train speed falls to such a value that the generator voltage falls slightly below that of the battery.

CHAPTER III

TESTS OF VARIOUS EQUIPMENTS

Test of Curtis Turbo-Generator Set

The test of this equipment was made on trains Nos. 1 and 6 of the Chicago, Burlington and Quincy Railroad, running between Chicago and Denver; the equipment consisting of a 25 K. W. Curtis turbo-generator set mounted in the front end of the baggage car, there being an auxiliary of two sets of batteries in connection, one located under the baggage car and the other beneath a Pullman car at the rear of the train. The turbine receives its steam from the locomotive through a pipe line located beneath the cars and a flexible hose connection between cars, there being a reducing valve at the locomotive which reduces the steam pressure from boiler pressure to 80 pounds per square inch at the turbine.

The turbo-generator set is one manufactured by the General Electric Co. and is of 25 K. W. capacity, type C–2–25–3600–Form–T, amperes 200. The turbine is equipped with a governor which automatically regulates the speed by opening or closing poppet-valves controlling the steam supply. The steam after leaving the turbine exhausts through a steam funnel into the air above the car, the funnel serving to drain back the water in the steam, thus preventing an undue collection of ice on the cars in the winter time.

The *switchboard* is conveniently mounted in the dynamo compartment and contains an ammeter and voltmeter of the Weston type, two gauges, one for reading the pressure of the steam as delivered to the turbine and another of lower scale to register the pressure as delivered to the train pipes for heating the cars.

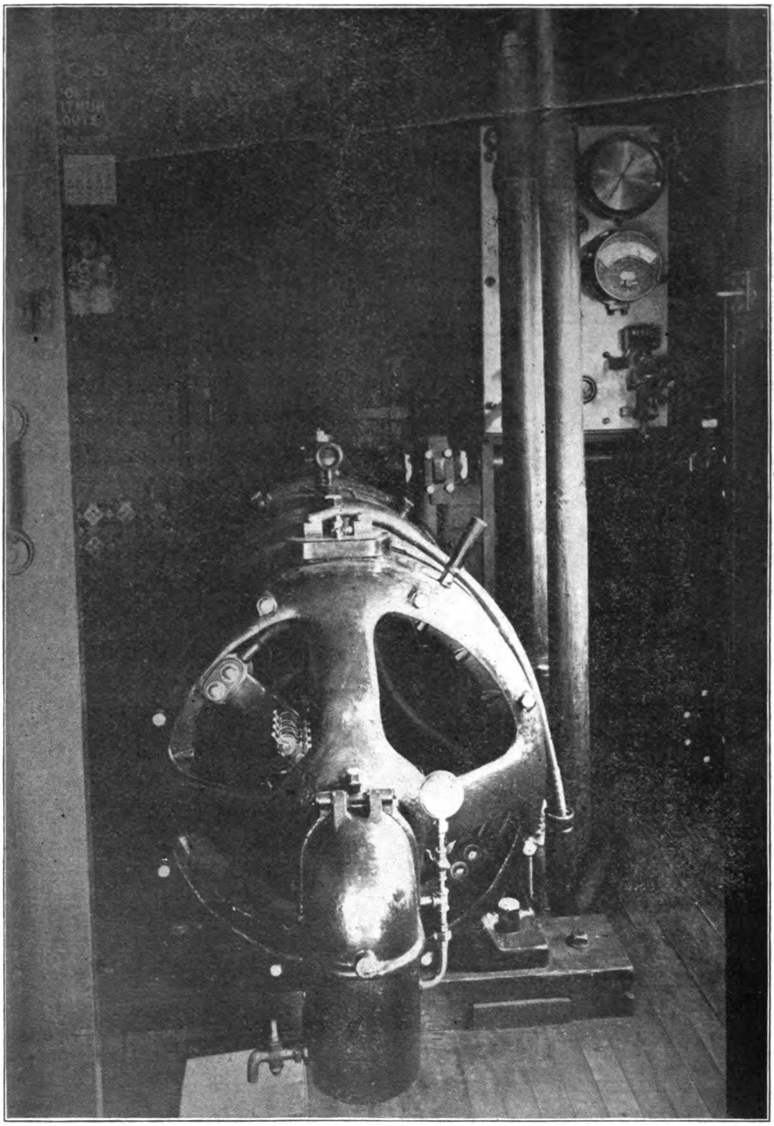

PLATE IV.—CURTIS TURBO-GENERATOR SET, C. B. & Q. RY.

The switchboard also contains an automatic circuit breaker designed to protect the generator against both overload and reverse current. The under load (reverse current) attachment is provided so that in case the steam pressure is shut off and the generator becomes inoperative, the circuit will be automatically opened as the speed decreases, thus preventing the generator being driven as a motor by the batteries.

The *batteries* consist of two sets, one located on the baggage car and one on a rear Pullman car. They are of the type 13–E made by the Electric Storage Battery Co. and are of 240 ampere-hours capacity, there being 54 cells supplied to each battery. These batteries are floated directly on the line, thus adding to the simplicity of the system in that they require no switches to be thrown to place them on the line when the turbine is cut off, but they are always ready for the service of supplying current to the lights.

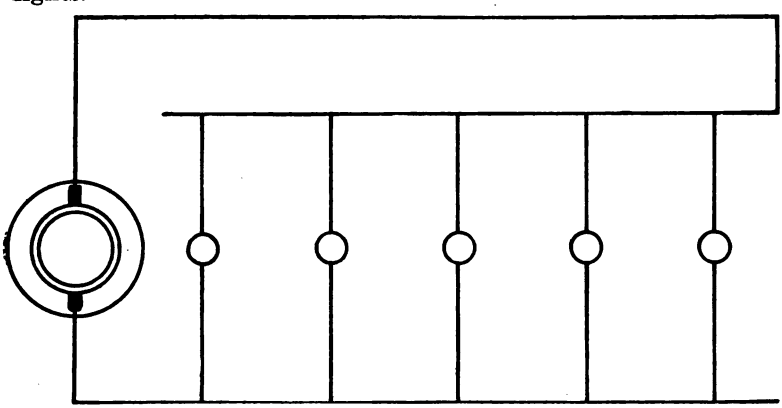

PLATE V.—SHOWING ARRANGEMENT OF THE TRAIN LINE.

The *train line* is arranged in the manner known as the return loop or Wirderman construction, and consists essentially of three wires running throughout the length of the entire train, being located in the roofs of the cars; the positive wire, as illustrated in Plate V, running to the rear of the train from whence it loops back along the same path to the forward car of the train, the lights and batteries being connected between this return loop and the third wire which is connected directly to the negative

brush of the armature. The object of this construction is to obtain a more uniform distribution of potential to the lamps along the line.

There is another feature in the train line construction, which, though common in train wiring, deserves special emphasis; it is that the two feeding wires are crossed within each car and also between every two cars. This is to preserve proper polarity to each of the wires within the car. The necessity for this is best shown by a comparison of the three figures of Plate VI. In Fig.

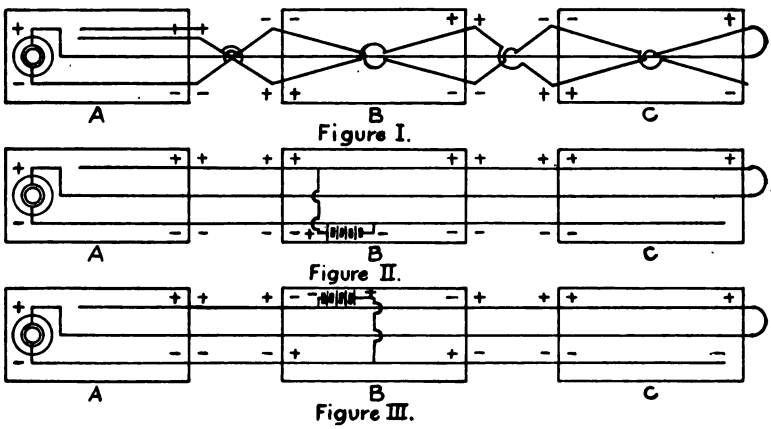

PLATE VI.—ILLUSTRATING THE CROSSING OF THE TWO FEEDING WIRES.

I is shown the train line as in operation. It is obvious that no matter which end of the car (B) is forward the same polarity of the generator will be presented to the batteries located on that car. It is also readily seen that, if the train had been wired straight as per Fig. II, a battery being located on the middle car, and that car were turned end for end as in Fig. III, the positive generator lead would be presented to the negative terminal of the battery and the negative terminal of the battery to the positive lead from the generator; thus causing a direct short circuit of the generator and battery through each other.

The *connectors* between cars are of a special type designed for this purpose, consisting of male and female parts, each of which has three insulated connections for accommodating the three train wires.

PLATE VII.—DINING CAR, DENVER LIMITED, C. B. & Q. RY.

There is a hard rubber block between the two positive leads to insure against putting in the male connector upside down. A thumb screw clamps the male solid after it is inserted into the female block and insures good and permanent contact. The leads between cars are of heavy flexible copper cables and are looped up and fastened to one side of the passageway, so as not to interfere with the traveling public.

Each car is equipped with an individual switchboard containing switches for each of the lighting circuits, as well as fuses for the same, and in cars containing batteries there are switches for the battery and the train line.

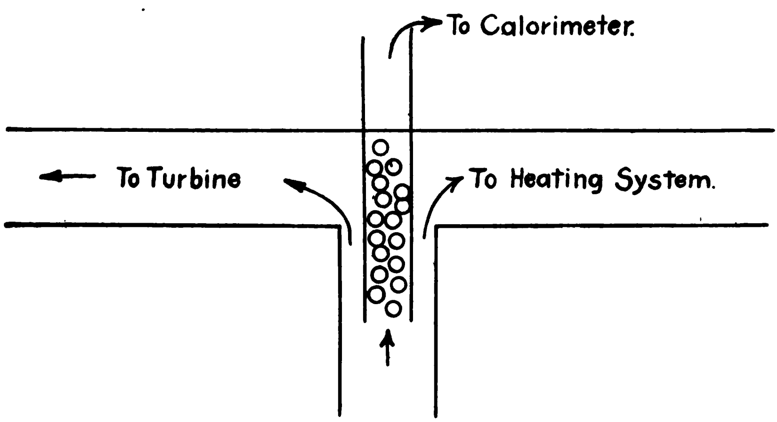

PLATE VIII.—SHOWING CALORIMETER TOP, CURTIS TURBINE TEST.

An electrician is placed in charge of the equipment and is on the train throughout the whole trip, his duty being to maintain the voltage constant and to care for any emergencies in the operation of the equipment as well as to maintain proper steam pressure on the train heating system.

METHOD OF TEST

Two distinct tests were made of this equipment:—one a road test to determine operating conditions of the equipment and the other, a steam consumption test to determine the amount of steam consumed from the locomotive boiler in the operation of the equipment.

For the *road test* the turbine was equipped with a calibrated steam gauge, and a separating calorimeter to determine the pressure and quality of the steam. The pressure gauge was located in the pipe line about a foot from the turbine steam chest. The separating calorimeter tap was located in a "T" pipe connector, illustrated in Plate VIII, at the point where the steam is first carried into the engine room by the pipe line from the locomotive boiler, and before it has passed through the separator, so no consideration was made of the separator water, this being all included in the moisture of the steam as indicated by the calorimeter.

In order to determine the electrical operation of the equipment, a calibrated ammeter was placed in the generator circuit and a calibrated voltmeter was connected across the terminals of the generator. The speed of the generator was determined by means of a stop watch and speed indicator. Readings were taken at 15 minute intervals throughout the whole time of generator operation. When the lights were on the batteries, readings of voltage and current at each battery were taken, also the total time of operation of the same.

In addition to the above data the pressure of oil on the bearings was noted occasionally, the gauge already installed on the turbine being used for taking such readings.

Yard Test for Steam Consumption

After equipping one of the turbine sets for a test in the yards at Chicago it was found that not sufficient cooling water could be obtained to condense the steam used. Accordingly it was determined to make this test at the steam laboratory of the University of Wisconsin where there has this year been installed a turbo-generator set identical with the one tested on trains Nos. 1 and 6. In making this test the turbine was operated under the same voltage as is usual on trains Nos. 1 and 6.

A surface steam condenser of the Blake type of a capacity of 2,000 pounds of steam per hour was connected up to the exhaust pipe and used to condense the steam used in driving the turbine. This condensed steam was run into tubs where it was

weighed on standard Fairbank's platform scales at intervals of exactly five minutes each, so that the steam used for each five minutes might be determined.

The *load* was applied to the generator by means of a water box, and voltage and current were measured by calibrated Weston instruments.

The pressure and quality of the steam were determined by a pressure gauge tapped in very near the turbine and by means of a throttling calorimeter tapped into a vertical section of the pipe at the turbine. The back pressure was read on a manometer tube tapped into the exhaust pipe. The speed was determined by means of a stop watch and speed indicator. Data were taken of each of the above at the various loads of ¼, ½, ¾, full, and 1¼ load for the several steam pressures of 60, 70, 80 and 90 pounds per square inch, respectively; readings being taken for periods of 30 minutes each, keeping the steam pressure and load constant.

Discussion of Results

Referring to the curves on Plate IX, the most striking result of the test on the road is the fact that the generator load is never above 17 K. W. and the average load is less than 11 K. W., while the generator set is of 25 K. W. capacity. There are, however, several reasons for the selection of this equipment of large capacity, in regard to which it may be said by way of introduction that the efficiency of operation is not merely the relation of out-put to in-put, but in service on the railroad a number of other considerations enter in to make efficiency or cost of operation of secondary importance. For instance, it is necessary that the railroad be prepared to handle very heavy traffic at certain rush seasons, in many cases doubling the size of its passenger trains, thus requiring a proportionally heavy lighting capacity, which, though lasting for a few days only, must still be taken into consideration in determining the capacity of equipment.

Still another condition which warrants the use of a set of such large capacity is the low steam pressures, say 60 pounds per square inch, which often occur, the turbine then being able to

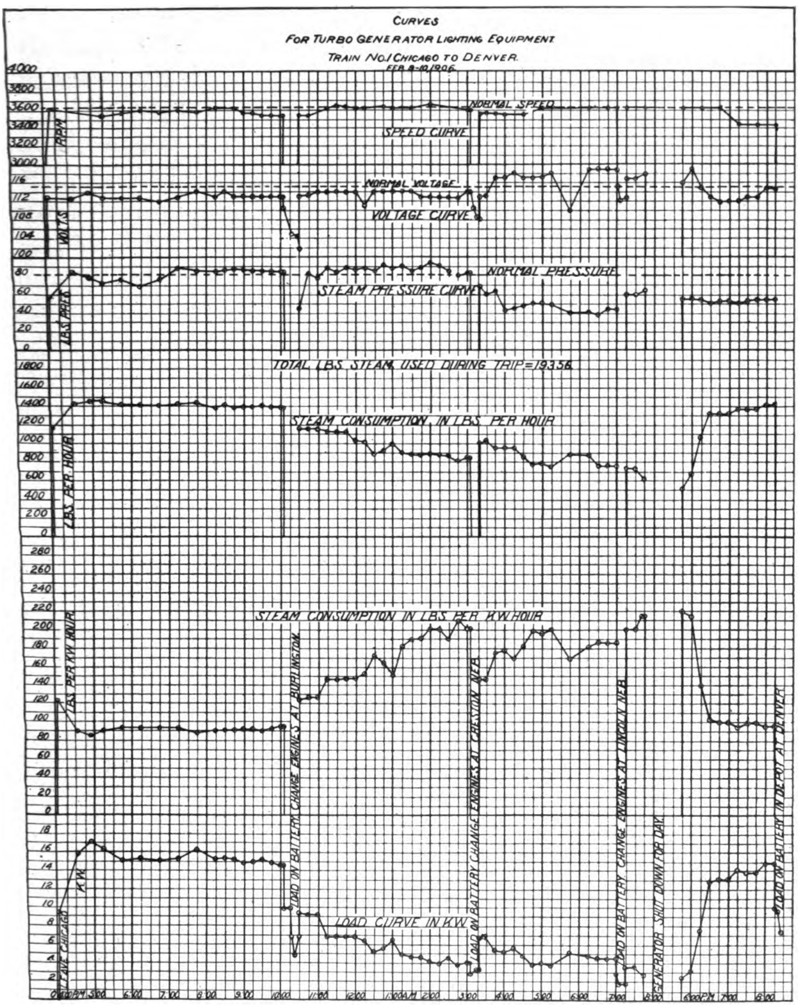

PLATE IX.—CURVES FOR TURBO-GENERATOR LIGHTING EQUIPMENT.

deliver only ½ or ¾ of its normal full load. Under such conditions a 25 K. W. set will still carry the load of lights in a train, but a 15 or 20 K. W. set would not be able to carry the load of lights. Another fact which deserves attention is that the gross steam consumption over the whole trip does not vary as much as might be expected, from full load to the lighter loads, as shown by a consideration of the curve of steam consumption, plotted in pounds of steam consumed per hour, Plate IX, the maximum variation of gross steam consumption being from 1,460 pounds per hour at 17 K. W., to 550 pounds at 2.5 K. W.

It is readily seen from a comparison of curves of load and of steam consumption per K. W. hour that the steam consumption per K. W. hour varies inversely as the load; this tending to make the total steam consumed more nearly constant at the various loads.

Discussion of Steam Consumption Test

Referring to the curves of Plate X, the results of the steam consumption test show some remarkable features. In the first place it was found that the steam consumption curves for all the pressures employed were almost identical, that is, that for variations of steam pressure between 60 and 90 pounds per square inch the steam consumption is independent of the steam pressure. This is indicated by the fact that all the points determined lie on the same curve. The only explanation for this peculiar result that can be offered is that a throttling action may take place in the governor, which tends to maintain the pressure on the nozzles more or less constant, irrespective of the pressure in the steam pipe.

The steam consumption is higher than is to be expected from a reciprocating engine of a similar capacity, but an explanation of that fact is not within the limits of this investigation.

This matter of high steam consumption was taken up with the General Electric Co. A representative was sent to Madison to inspect the turbine which had been tested, and he replaced the steam nozzles with some of a newer type, and a following test was made.

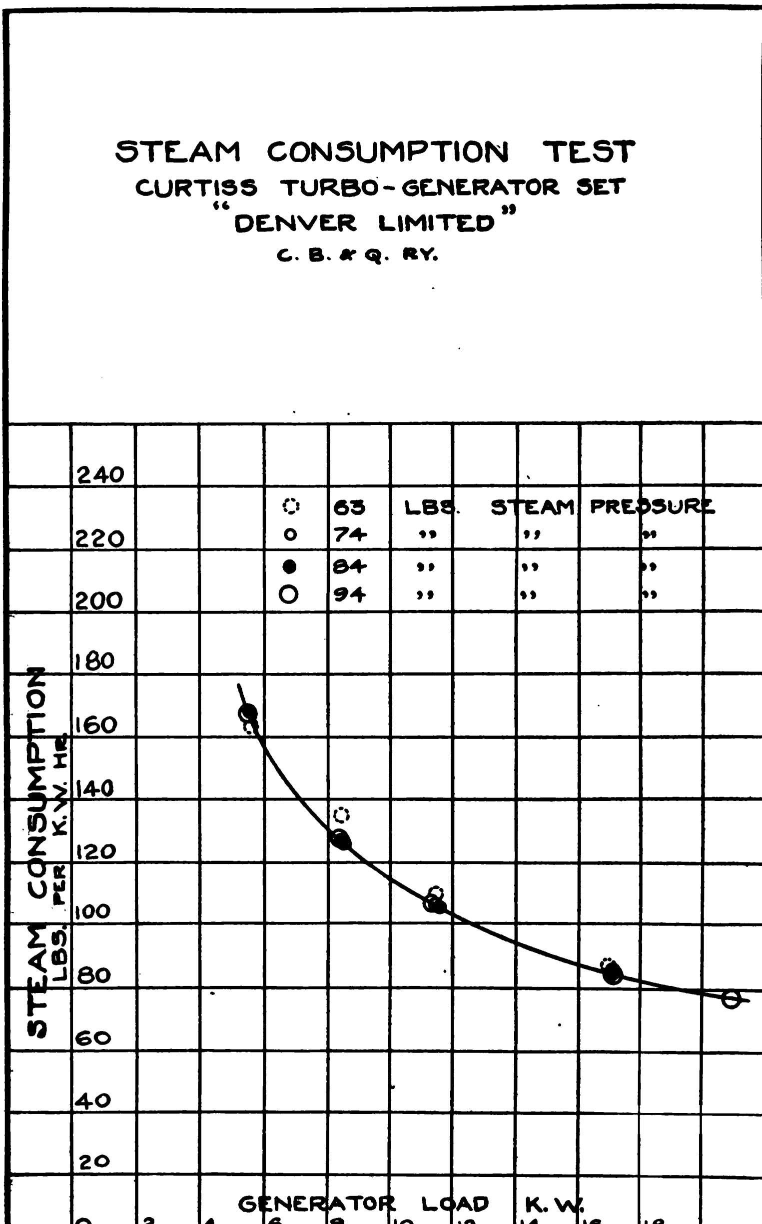

PLATE X.—CURTISS TURBO GENERATOR SET. CURVES OF STEAM CONSUMPTION.

Readings were taken at five minute intervals during a run of one-half hour. The turbine had been in operation before the test started so that all parts were thoroughly warmed. The results were as follows:

Average volts	125.4
Amperes	200.0
Speed R. P. M.	3403.
Steam pressure, pounds per square inch	80.
Quality of steam, per cent.	98.3
Total steam consumed, pounds	846.5
Average load, K. W.	25.08
Total wet steam consumed per hour, lbs.	1693.
Total dry steam consumed per hour, lbs	1662.
Total dry steam consumed per K. W. hour, lbs	65.4
Total dry steam consumed per E. H. P. hour, lbs	49.5

This shows a considerable improvement in the steam consumption over the conditions found in the first test, (about 8 per cent. at full load) and so due reference is made to it here, showing the possibility of the turbine with the improved nozzles. Accordingly, the nozzles on the turbines in the Burlington Railroad equipments have been replaced by the newer ones since our tests were made.

According to our records, 19,356 pounds of steam were used in lighting the train from Chicago to Denver, which is approximately three per cent. of the total water supplied to the locomotive boiler as indicated from the number of tank fillings.[1]

WESTINGHOUSE ENGINE GENERATOR SET.

ON NORTH COAST LIMITED, NORTHERN PACIFIC RAILWAY, ST. PAUL TO PORTLAND, OREGON, DECEMBER 23 TO 31, 1905

The equipment consists essentially of a Westinghouse Standard engine located in the forward end of the express car which

[1] The complete data of this test can be found in the graduating thesis of A. U. Hoefer and Edgar Kearney, University of Wisconsin, 1906.

drives a generator in direct connection, receiving its steam from the locomotive through a pipe line and flexible hose connections, there being an automatic pressure reducer on the locomotive which is supposed to maintain a pressure of 80 pounds at the generator set.

An auxiliary storage battery is supplied to each car except the mail and express cars. These batteries were not floated on the line continually as was found in the equipment on the Denver Limited in the test previously described but were wired so that they could only be thrown on one circuit of lights, and were not in connection with the train line except when they were thrown on to light the lights or when they were charged at night.

The batteries received a charge each night when most of the lights throughout the train had been turned off, by raising the generator voltage to 115 volts and maintaining it constant at that value for several hours. This provided 2.3 volts per cell which will if continued long enough very likely fully charge the batteries.

The batteries are also fully charged to 130 volts once a week when the train is being cleaned in St. Paul, the current being kept constant at 50 amperes.

The *train line* was of the three wire return loop system described on page 29 of the previous test and will not be considered further here. An electrician who remains on the train over the whole round trip, is placed in charge of the equipment.

Method of Test

The method of testing was very similar to that of the previous test. A road test was made to determine the operating conditions, and this was supplemented by a steam consumption test in the yards under the conditions of operation experienced on the road.

In the *road test,* readings were taken at fifteen minute intervals of generator speed, voltage and current, steam pressure, steam quality, separator water and indicator cards.

The first five mentioned were all taken by means of calibrated instruments from the laboratory of the University of Wisconsin.

Separator water was tapped off from the "Cochrane" separator supplied permanently to the engine, and weighed on a spring balance. The engine was indicated by means of a special link mechanism consisting of a pair of cranks, connecting rod, and piston rod sets in the exact relation as existed between those inside the engine. This mechanism was then bolted to the end of the shaft so that the small piston rods would reproduce the motion of the engine piston rods within the engine. The indicators were placed on top of the cylinder heads in place of the poppet relief valves and the indicator motion was transmitted from the link mechanism by cords. A heavy spring was added to the indicator cord so as to keep it very tight, to care for the vibration due to the high speed of 400 R. P. M.

The *yard test* consisted in making a measurement of the steam consumption under conditions as they were found on the road test. The steam from the engine exhaust was run into a surface condenser and collected in tubs and weighed on platform scales. Each test consisted of a run of twenty minutes duration, during which time the load and steam pressure were kept constant, these tests being made for loads of ¼, ½, ¾, and full load and for the different steam pressures of 42, 50 and 85 pounds per square inch, respectively.

The road test was made in duplicate by two different parties on two different trains, while the steam consumption test was made for only one equipment.

The plotted curves of the road test which are here exhibited are for one night's operation on one equipment only, this set being selected as typical.

CAR NO. 241

Night.	K. W. hrs., load.	Total wt. of steam.	Separator water.	Av. lbs. stm. per hour.	No. hrs. run.	Av. load in K. W.	Av. steam, lbs., K. W. hr.
1 West	149.85	15,930	720	980	16.2	9.22	106.4
2 West	161.5	15,750	420	900	17.5	9.24	97.5
3 West	144.1	15,740	400	1,000	15.7	9.16	109.2
1 East	156.5	15,860	717	1,005	15.7	9.25	101.0
2 East	154.1	11,480	635	730	15.7	9.7	75.4
3 East	159	15,030	947	1,002	15.0	10.6	94.7
Total	925.05	89,790	3,839	936	96.0	9.65	97.3

CAR No. 237

Night.	K. W. hrs., load.	Total wt. of steam.	Separator water.	Av. lbs. stm. per hour.	No. hrs. run.	Av. load in K. W.	Av. steam, lbs., K. W. hr.
1 West	109.7	10,530	586	660	16	6.87	96
2 West	121.4	13,750	592	860	16	7.59	113
3 West	120.4	15,810	623	1,003	15.75	7.65	131.2
1 East	145.2	16,300	934	1,002	16.25	8.95	112.2
2 East	119.4	13,775	666	950	14.5	8.24	115.4
3 East	114.2	15,460	731	1,030	15	9.63	107.3
Total	730.3	85,625	4,132	916	93.5	8.17	112.

DISCUSSION OF RESULTS

Attention should first be called to the results of the yard test shown in Plate XII. It is seen that the steam consumption for 42 pounds steam pressure is much higher than it is for 83 pounds pressure at the same load. This is due to the fact that the governor on the engine is one for constant speed and in its efforts to maintain this constant speed at the low pressure it increases the admission. Some cards taken at low pressure showed admission of steam to the cylinders for more than three-quarters of the stroke.

The steam consumption at the higher steam pressures is reasonable and about what might be expected from the type of engine.

Referring to the road test curves on Plate XI, attention should be called to the high peak in the steam consumption curve at 6:00 P. M. This is due to the fact that the load was great and at the same time the steam pressure was very low, as is shown by the corresponding curves.

There is an interesting note in connection with this fact. The locomotive engineman in his efforts to relieve his own engine, throttles the steam connection to the generator set, but in fact in doing so he only increases the drain he intended to lessen. If he had given the generator full pressure instead of throttling it lower, he would have really lessened the steam consumption and at the same time afforded better operation of the lighting equipment. It should also be noted that the steam consumption

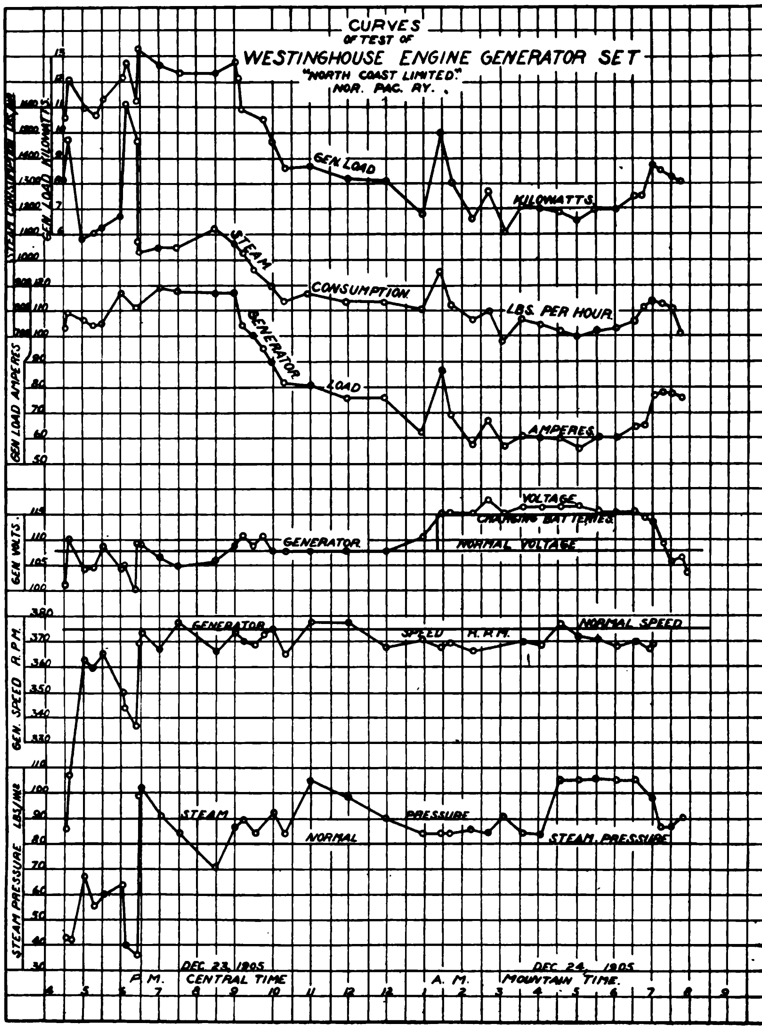

PLATE XI.—CURVES OF TEST OF WESTINGHOUSE ENGINE GENERATOR SET, NOR. PAC. RY.

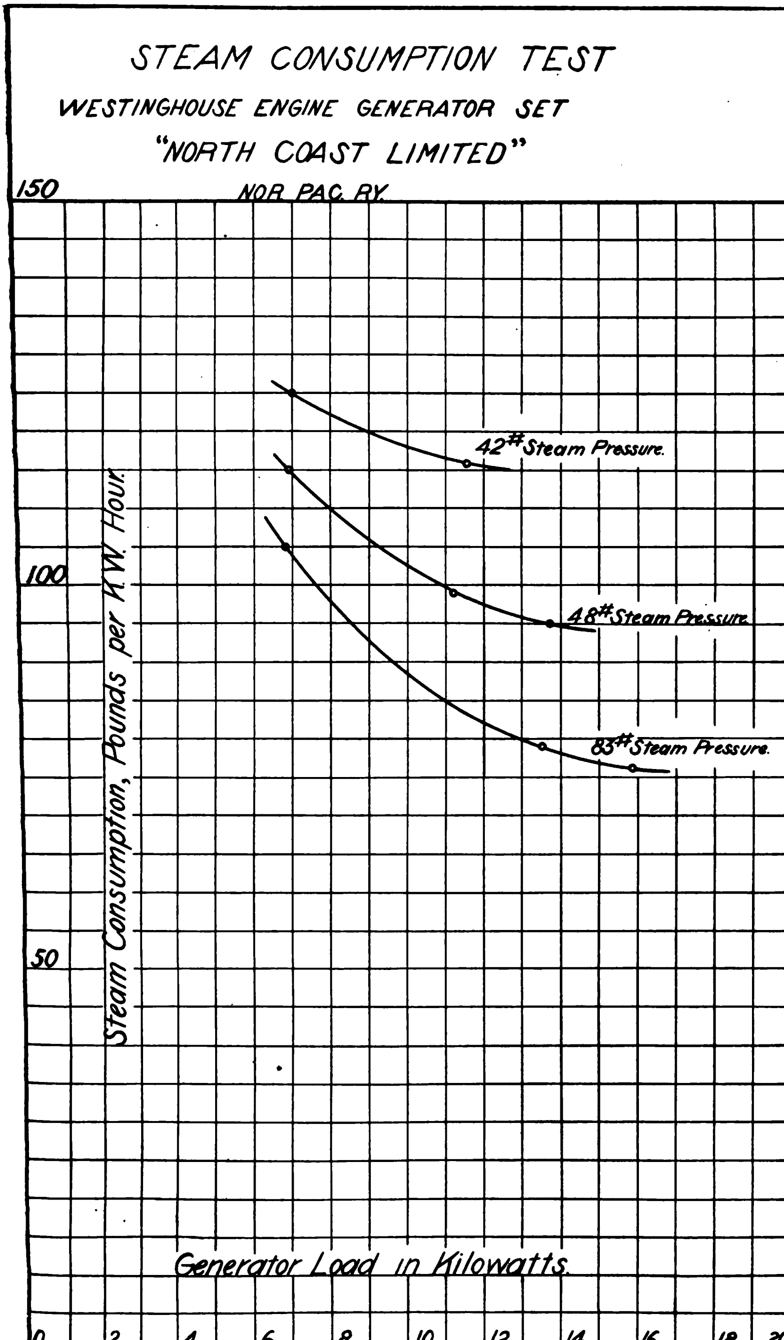

Plate XII.—Steam Consumption Test, Westinghouse Engine Generator Set.

does not follow the load curve directly, but tends to remain more constant.

Both the engine speed and generator voltage are affected by variations in steam pressure and are seen to follow the steam pressure curve almost directly, especially where low steam pressure occurred. The generator output is often affected as shown by the curve at 6:00 P. M. This fact is one of the main causes of failure of this equipment in that the engineer throttles the steam supply and causes the generator to fail in maintaining proper lighting of the train and at the same time really increases the drain on the locomotive. This point cannot be given too much emphasis, as it is due to a wrong conception on the part of the enginemen and should be corrected.

It is seen by reference to the test on the Pioneer Limited, C., M. & St. P. Railway, that a very similar condition exists there.

In regard to the method of charging batteries on the road by raising the voltage to 2.3 volts per cell, it must be said that this seems to be about the best way to keep them up during the trip, though it is very destructive of the lamps lit at that time, the high voltage causing them to be strained, which spoils them for operation at the normal voltage.

The method might be adopted of charging in the daytime, but that would involve an extra run and additional drain on the locomotive and would be liable to cause trouble with the enginemen.

The charge every week at St. Paul, in which the batteries are fully charged, is sufficient to keep the batteries from becoming permanently sulphated.

In regard to the steam connections, it must be said that considerable trouble was experienced. The flexible connection between the cars consisted of a combination of the Moran metallic coupling and the Martin flexible joint. We found the greatest trouble in the Martin joints. When the Moran coupler was properly locked it gave little or no trouble. The Martin joint is in the form of a ball and socket joint, made up of a bell shaped piece, which is inserted in a Vulcabeston packing ring, and is free to move more or less in all directions.

There were eight of these connections between the dynamo and locomotive which were in constant need of attention.[2]

Test of Westinghouse Engine Equipment

Pioneer Limited, C., M. & St. P. Ry.

The equipment under consideration is very similar to that of the two tests on the Northern Pacific and the Chicago & Northwestern railways, consisting of a high speed Westinghouse Engine Generator Set mounted in the forward end of the baggage car and supplied with steam from the locomotive at 80 pounds pressure per square inch.

The C., M. & St. P. Railway was the first to adopt this method of train lighting. One of the earlier equipments consisted of a separate car known as the "Light and Heat Tender," which in the winter months supplied both light and heat for the train, but was in the summer months replaced by an ordinary baggage car equipped with a generator set. This gave satisfactory results but was ultimately abandoned (in that it required an extra car and attendant) and the duties of supplying light and heat were placed upon the locomotive, resulting in the present equipment.

The equipment tested consisted of a 25 K. W. generator set placed crosswise of the end of the car to reduce the train vibration caused by the set. This is at times very objectionable and can be felt often times throughout the entire length of the train, hence this location of the generator set is made to minimize this. The shafts of the baggage car generating sets of the Northern Pacific and Chicago & Northwestern roads, are placed longitudinally within the car. A storage battery is supplied as an auxiliary to maintain the lights when the locomotive is disconnected at engine changes.

The method of train wiring is similar to that of the Denver Limited described on page 30 and will not be considered further.

The equipment is placed in care of the baggageman who looks

[2] For the complete data of this test refer to the graduating thesis of W. A. Bertke and I. L. Reynolds, University of Wisconsin, 1906.

after the generator set, etc., in the baggage car, but the care of the train line is placed in the hands of the brakemen on account of the other duties of the baggageman making it impossible for him to leave his car.

METHOD OF TEST

In making the test of the equipment two round trips were made with the equipment between Chicago and St. Paul to determine the operating conditions on the road. This test was supplemented by a steam consumption test in the yards at Chicago, under conditions similar to those found in operation on the road.

In the road test, additional data were taken in connection with the heating of the train, but this is not within the limits of this thesis so will not be considered here.

In connection with the operation of the lighting equipment, however, data were taken of the following:—generator load voltage and speed, and engine steam pressure, quality of steam and quantity of separator water. The engine also was indicated in the following manner:

The safety plugs were removed and a stuffing box inserted through which a rod was passed and bolted to the piston head, thus transferring the motion of the piston head to the indicator motion which consisted of an ordinary link mechanism. Special holes were drilled in the cylinder heads to accommodate the indicators.

In the steam consumption test the steam consumed was determined by operating the set at constant load and constant steam pressure over a period of 15 minutes, readings being taken at five minute intervals of the steam used, steam quality and pressure, generator speed, voltage and current. The steam was condensed in a surface condenser and weighed in tubs on platform scales. Indicator cards were also taken at five minute intervals.

The results of the steam consumption test are given on Plate XIV.

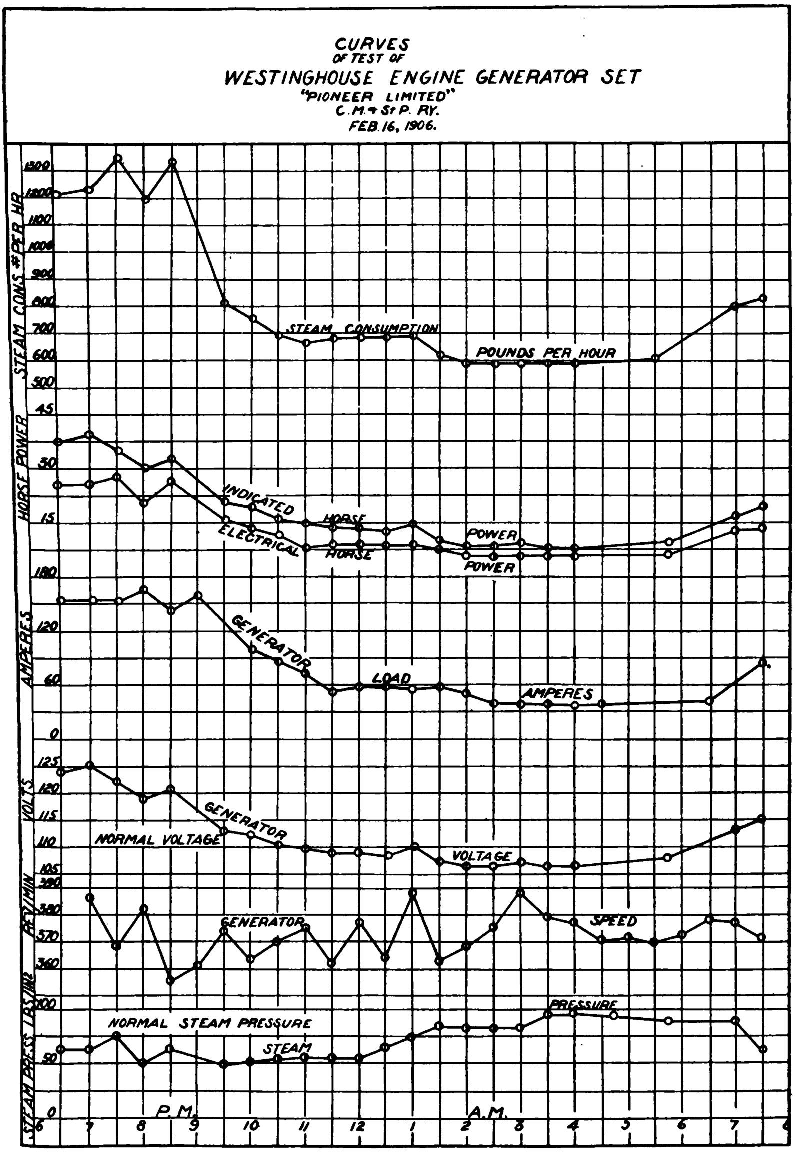

Plate XIII.—Curves of Test of Westinghouse Engine Generator Set, C. M. & St. P. Ry.

Results of Test

1st trip. Chicago to St. Paul, Feb. 14, 1906:

Average steam pressure	92	lbs. per sq. in.
Average load of lamps	8.7	K. W.
Average steam consumption	690	lbs. per hr.

2nd trip. St. Paul to Chicago, Feb. 15, 1906:

Average steam pressure	108	lbs. per sq. in.
Average load of lamps	8.9	K. W.
Average steam consumption	580	lbs. per hr.

3rd trip. Chicago to St. Paul, Feb. 16, 1906:

Average steam pressure	75.7	lbs. per sq. in.
Average load of lamps	9.8	K. W.
Average steam consumption	780	lbs. per hr.

4th trip. St. Paul to Chicago, Feb. 17, 1906:

Average steam pressure	90	lbs. per sq. in.
Average load of lamps	9.5	K. W.
Average steam consumption	770	lbs. per hr.

Discussion of Results.

In discussion of the results of this test it must be said that the operation is very similar to that experienced with the other similar equipments as discussed on page 41, except for the fact that this one shows somewhat more economical operation as seen by the comparison on Plate XLVI.

The high steam pressure of 115 pounds in the latter part of the trip should be noted, on Plate XIII. The generator voltage at the start of the trip was maintained high at a value of 125 volts, very likely to produce a good showing while standing in the depot before leaving. This during the night was allowed to fall off to 104 volts minimum.

The steam consumption curve is seen to follow the load curve very closely, it being however, higher at low loads than would be expected, due to the curve upward of the steam consumption per kilowatt-hour for low loads, as shown by the curve on Plate XIV.

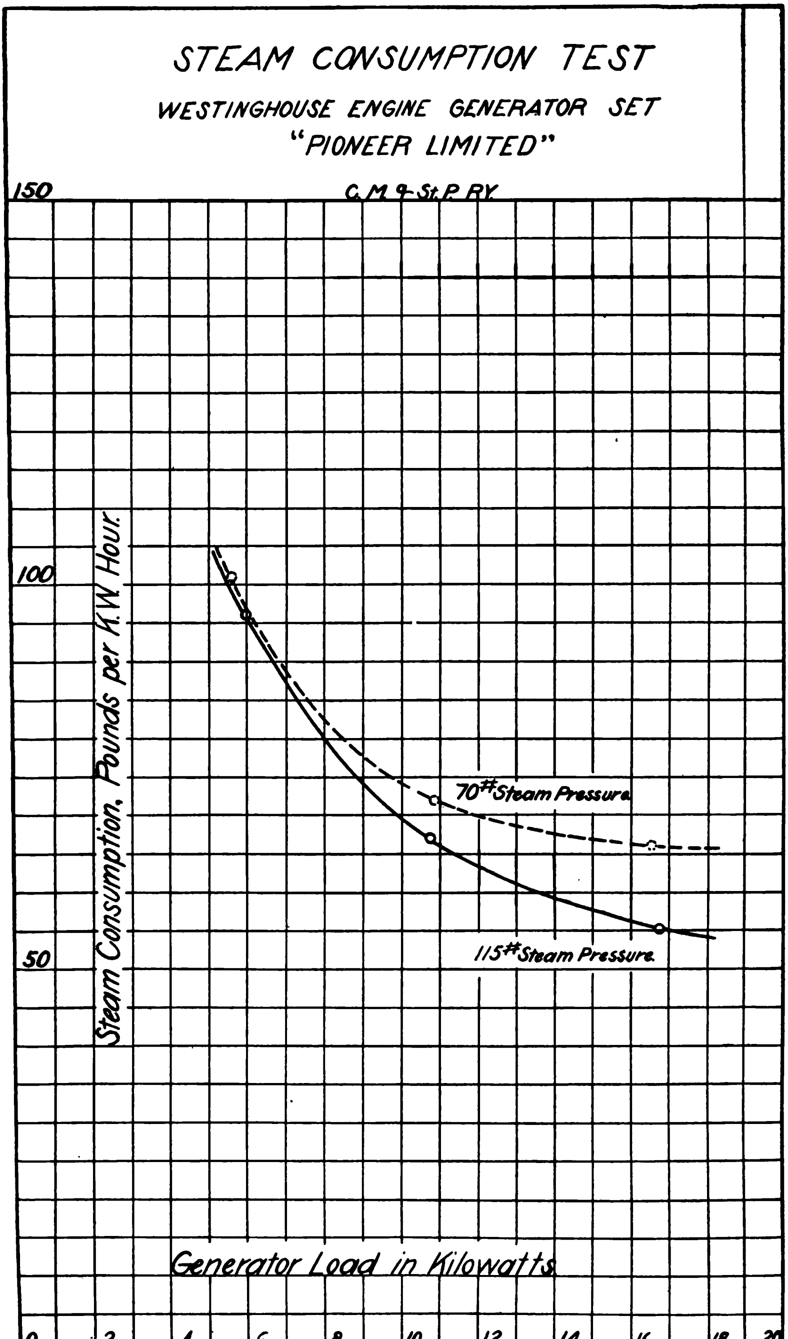

PLATE XIV.—STEAM CONSUMPTION TEST, WESTINGHOUSE ENGINE GENERATOR SET.

The relation between the curves of I. H. P. and E. H. P., Plate XIII, shows the mechanical and electrical efficiency of the set. In regard to the general operation of the equipment it must be said that at times the baggageman is too busy with his other duties to give the equipment proper attention, but in general the operation may be said to be satisfactory, the actual failure of lights being very infrequent, and at that time is generally due to the fact that the locomotive cannot provide enough steam.[8]

Test on Westinghouse Engine Generator Set

Northwestern Limited, C. & N. W. Ry.

This equipment is almost identical with those tested on the C., M. & St. P. Railway and Northern Pacific Railway, except that it has an auxiliary of Pintsch gas instead of storage batteries; and as there is only one engine change where this is required, this occurring in the middle of the night, the operation is satisfactory.

The equipment consists of a Standard Westinghouse engine, direct connected to a 17 K. W. generator operating at 400 R. P. M. and 110 volts.

The train equipment consists of the following:

Dynamo and Express Car, having..	8–12 c. p. lamps
Baggage Car, having	8–12 c. p. lamps
Compartment Sleeper, having	80– 8 c. p. lamps
Standard Sleeper, having	80– 8 c. p. lamps
Standard Sleeper, having	47–16 c. p. lamps
Dining Car, having	60– 8 c. p. lamps
Chair Car, having	36–12 c. p. lamps
Day Coach, having	22–16 c. p. lamps

Method of Test

The test on the road consisted in taking readings of current and voltage and steam pressure at fifteen minute intervals and

[8] For the complete data of this test refer to the graduating thesis of J. I. Bush and H. L. Heller, University of Wisconsin, 1906.

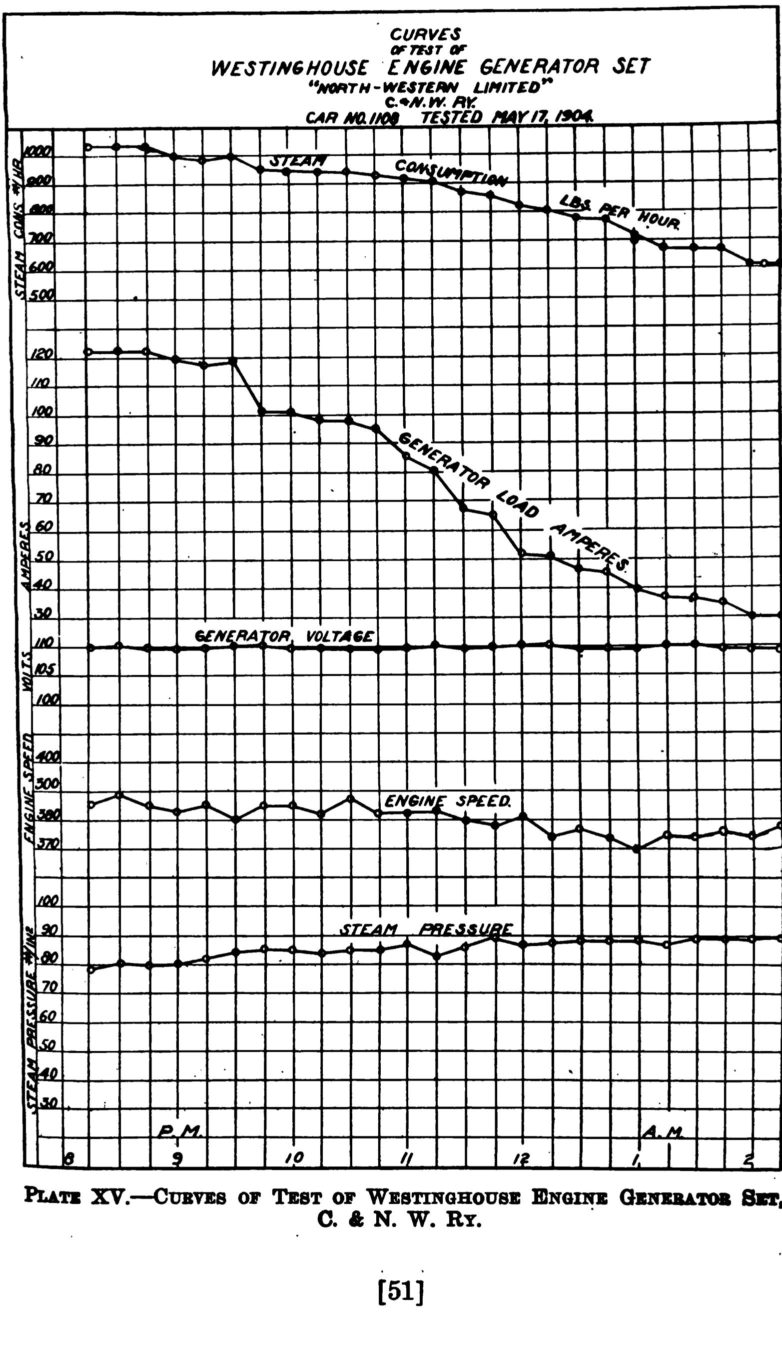

PLATE XV.—CURVES OF TEST OF WESTINGHOUSE ENGINE GENERATOR SET, C. & N. W. RY.

indicator cards and speed readings every ten minutes. The engine was indicated by a special link mechanism fastened to the end of the shaft very similar to that used on the Northern Pacific test.

A steam consumption test was made in the yards at Chicago in which the steam consumption was measured, keeping the steam pressure constant at 90 pounds per square inch and varying the load. Steam was condensed in a surface condenser and collected in tubs and weighed on platform scales. Each reading extend over a period of twenty minutes.

RESULT OF TEST

Trip from Chicago to St. Paul—Car No. 1108

Total duration of test	5¾	hours
Average load	8.2	K. W.
Average steam pressure	86	lbs. per sq. in.
Average steam consumed	870	lbs. per hour
Average steam per K. W. hour.....	106	lbs. per K. W. hour
Total steam consumed on test.....	5000	lbs.

DISCUSSION OF RESULTS

By reference to Plates XV and XVI the complete results of the test are graphically observed. It is noted from Plate XV that the steam pressure, speed and generator voltage are practically constant, and that the load decreases during the night from 122 amperes at 8:15 to 30 amperes at 2:15, when the lights were cut off.[4]

TEST ON CONSOLIDATED AXLE EQUIPMENT

NORTHERN PACIFIC RAILWAY

The axle driven equipment of the Consolidated, Kennedy type, consists essentially of a generator, pole changer, battery, regulator, automatic switch, and wiring and switches within the car.

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[4] For complete data of this test refer to the graduating thesis of C. S. Peters, University of Wisconsin, 1904.

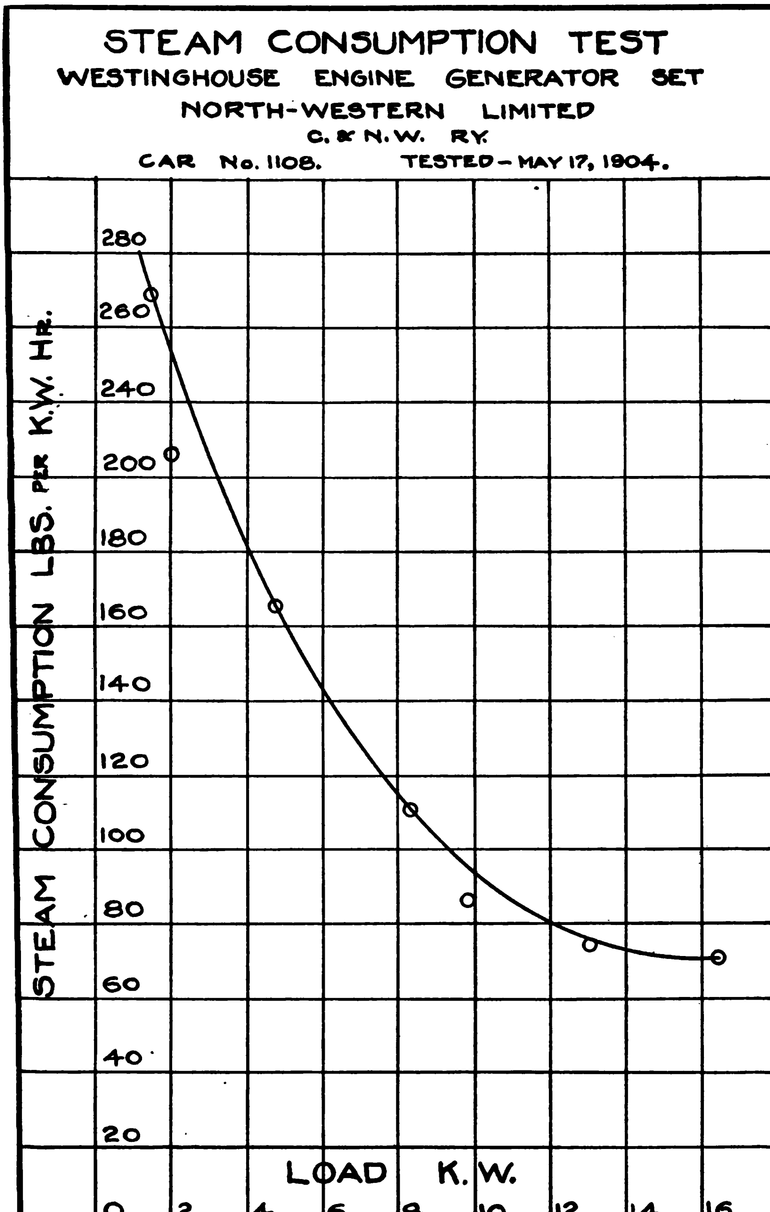
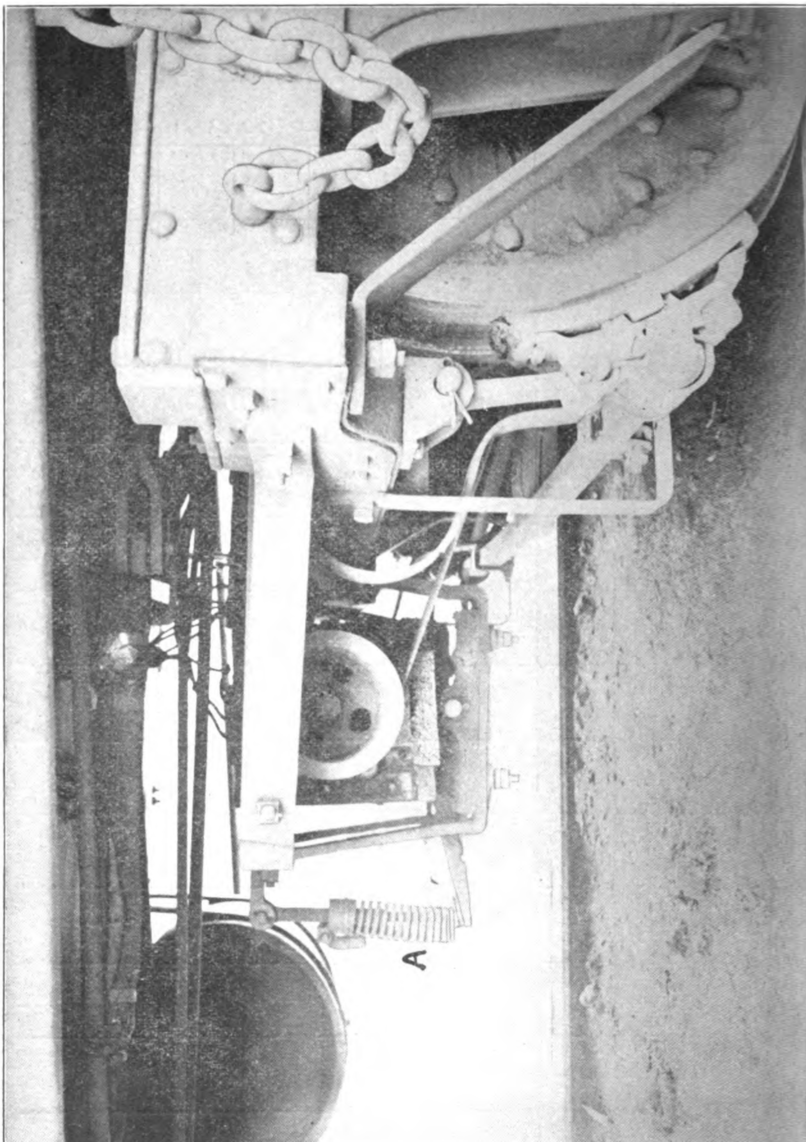


PLATE XVI.—STEAM CONSUMPTION TEST, WESTINGHOUSE ENGINE GENERATOR SET, C. & N. W. RY.


A

The generator is of bipolar, simple shunt-wound type and is provided with self-oiling bearings. It is encased in a dust-proof wrought iron casing which is provided with suitable covers and hand holes for repairs and inspection, and is suspended by irons bolted to the outer face of the forward truck sill (see Plate XVII) and pivoted on a rocker roller, a heavy adjustable spring, A, maintaining proper belt tension. The generator is belted to a large axle pulley (20½ inches in diameter) bolted to the axle. These pulleys are perforated to allow the sand and cinders to fall away from the belt surface. The generator field pieces are supplied with a few sheets of hard steel to insure proper polarity in the fields.

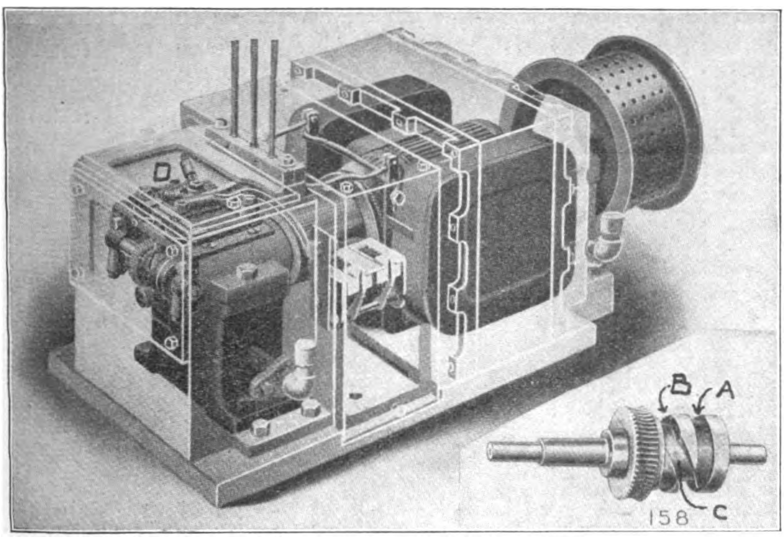


PLATE XVIII.—GENERATOR OF CONSOLIDATED AXLE EQUIPMENT.

The *pole changer* is that part of the appartus which maintains proper polarity in the circuit irrespective of the direction of motion of the car. This consists of a worm fitted on the armature shaft engaging with a worm-wheel on which is mounted a cam of peculiar construction, such that if the car motion be forward the cam follower will run continually in the slot A,

but if the direction of motion be reversed the follower will be forced through the diagonal slot C into the slot B, where it will remain as long as the direction of car motion is the same.

As the cam follower is forced from slot A to slot B it causes a reversing switch at D to be thrown, thus maintaining proper polarity in the external circuit. This is obviously essential to the operation of the equipment, for if the generator were thrown on the line with wrong polarity it would cause an immediate short circuit of both generator and battery.

The *battery* comprises 16 cells each of 240 ampere hour capacity of the type 13-E of the Electric Storage Battery Co., and is located under the car. The battery is connected in parallel with the generator and line, serving to act as an auxiliary in maintaining the lights lit while the generator is inoperative. The subject of batteries as applied to train lighting is discussed in a separate chapter in this report, so the subject will not be considered further at this point.

KENNEDY REGULATOR

The regulator is an important part of this equipment from a technical point of view. It is shown on Plates XIX and XX and the details of the wiring on Plate XXI.

The principle on which the regulator is based is that of generator control by variable field resistance and lamp voltage control by means of a variable resistance in the lamp circuit.

The generator control is effected by means of the pair of solenoids A, A, B, B, (Plate XX) in which there is a floating plunger which operates the pair of cam followers C on opposite sides of the cam E.[5]

When regulation is necessary, one of the followers C is drawn up against cam E and this cam being driven by a motor with worm-wheel connection to the shaft G, drives the follower and causes it to turn one of the pair of rachet wheels R, Plate XIX, operating the field resistance inside of H.

[5] A similar cam and pair of followers are located under the coils A, A as is shown under coils D, D.

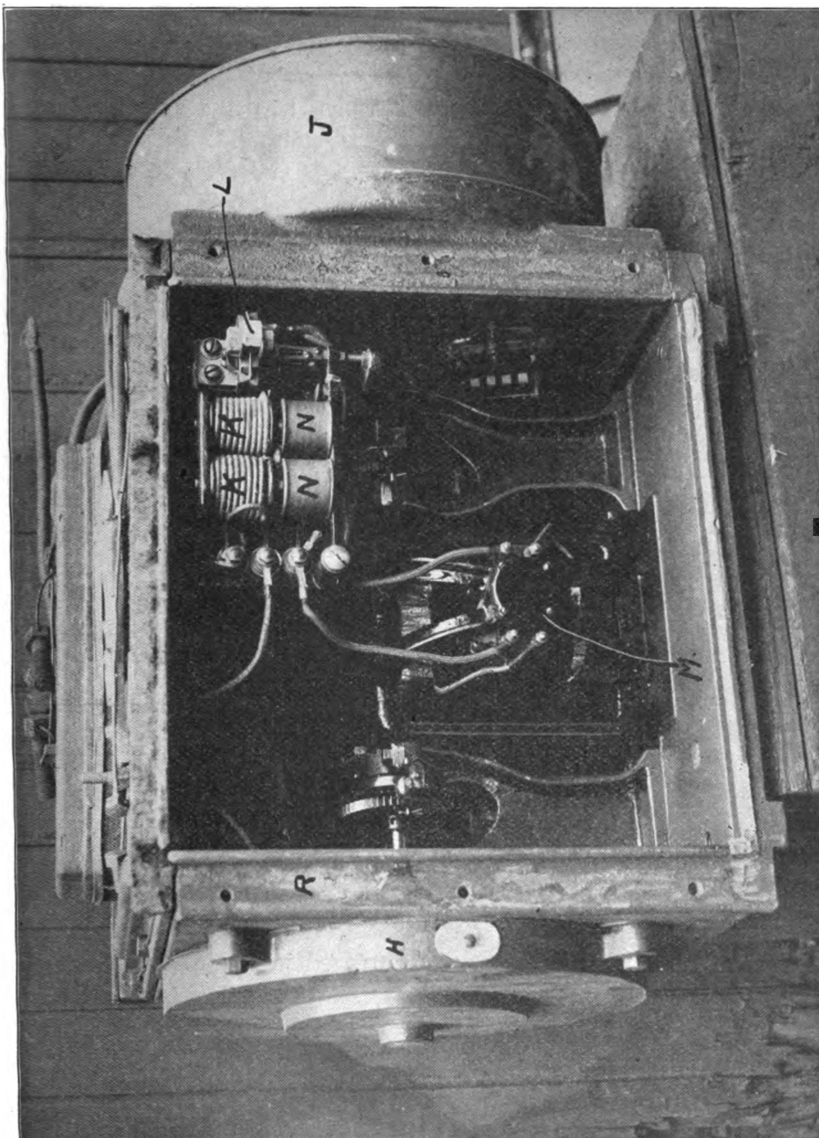


PLATE XIX.—KENNEDY REGULATOR.

The controlling solenoid includes a double set of windings, those A, A, in the main generator circuit and those B, B, placed in the lamp circuit, being connected so that the magnetism of coils B, B, is in opposition to that of coils A, A. This allows the generator current to be increased when the lights are turned on, thus permitting the batteries to be charged somewhat at night and still not have the day charging rate be excessively high.

The lamp voltage control is effected by means of the pair of solenoids D, D, Plate XX, which are wound with fine wire and placed across the terminals of the lamp circuit. The mechanical operations are identical with those of the generator current controlling devices, the floating plunger governing the operation of the large rheostat, J, which contains the lamp circuit rheostat. This regulator has the distinction of being the only one in which the lamp regulation is entirely independent of the condition of the batteries as well as the number of lamps in use; but it is dependent upon the operation of several moving parts as well as the proper adjustment of the spring, S, for its successful operation.

The *automatic switch* is that part of the equipment which connects the generator with the lights and battery when its voltage has risen so that it is slightly above the battery voltage. It is shown in Plate XIX. The coils N, N are mounted on a movable arm pivoted at T on which is supported the lower contact point of the switch, L. These coils N, N are wound with fine wire and placed across the terminals of the generator so that when the generator voltage rises to slightly above that of the battery the magnetism developed in these coils will draw up the movable arm and close the contact at L. The coils K, K are wound with coarse wire and are placed in the main circuit of the generator so that as soon as the switch is closed at L the current flowing through these coils will immediately intensify the magnetism of the coils N and insure good contact at the switch.

These series coils have also a function in opening the automatic switch at the proper time. As the generator voltage falls on decrease of train speed, till its voltage is below that of the

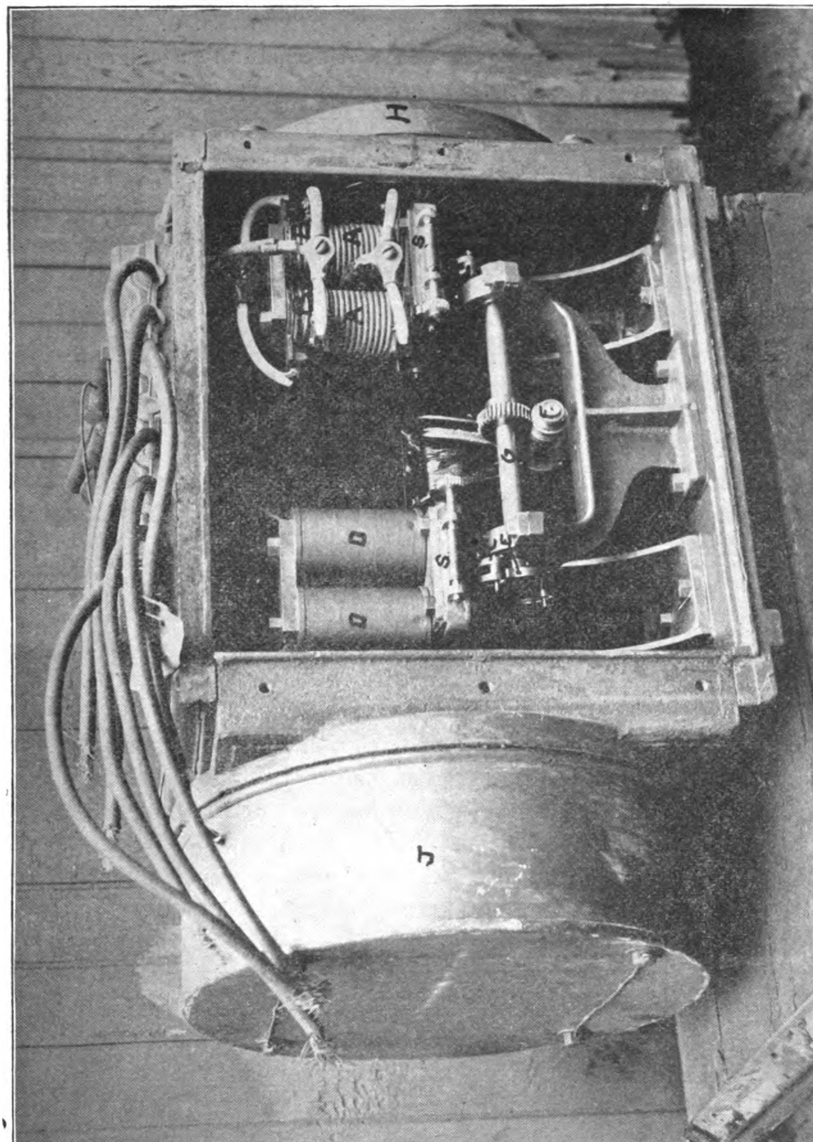


PLATE XX.—KENNEDY REGULATOR.

battery, a reverse current will flow through the coils K, K, creating a magnetic flux in opposition to that of the coils N, N, so that the opening of switch will be actually accelerated by the repulsion of the coils.

METHOD OF TESTING

The problem of testing such an apparatus in actual operation on a railway train is a peculiarly difficult one. In the first place everything in the system is in continual fluctuation, the speed of a railway train is well known to be an extremely variable factor, and it may be said that everything in the system fluctuates with train speed, though in justice to the manufacturers of the equipment it must be said that the limits of fluctuation of generator pressure and current for change in speed are small. In addition to this the generator is alternately thrown off and on to the circuit at every stop and start, the lights being fed at one minute from the generator and another from the battery, so that the equipment presents a rather chaotic condition to one endeavoring to obtain a comprehensive set of results.

It was decided to take two different kinds of data, one of which might be called *Detail Data*, which consider the detail operation of the equipment and include those data which when plotted in curves show the relation between train speed, generator voltage, lamp voltage, battery voltage, field voltage, generator current, lamp current, battery current and field current; and the other of which consists of *Wattmeter Data*, including the total generator output, total consumption of energy by the lamps, total energy of battery charge and total energy of battery discharge, over the entire trip.

In order to facilitate taking the data a switchboard was constructed as shown in Plate XXI, which made it possible to take the whole set of readings within the time of ten seconds. This switchboard contained all the numerous switches and instruments used in making the test as shown by Plate XXI, and was placed in a double seat at that end of the car in which the regulator was located.

In wiring to the regulator, heavy insulated copper cables were

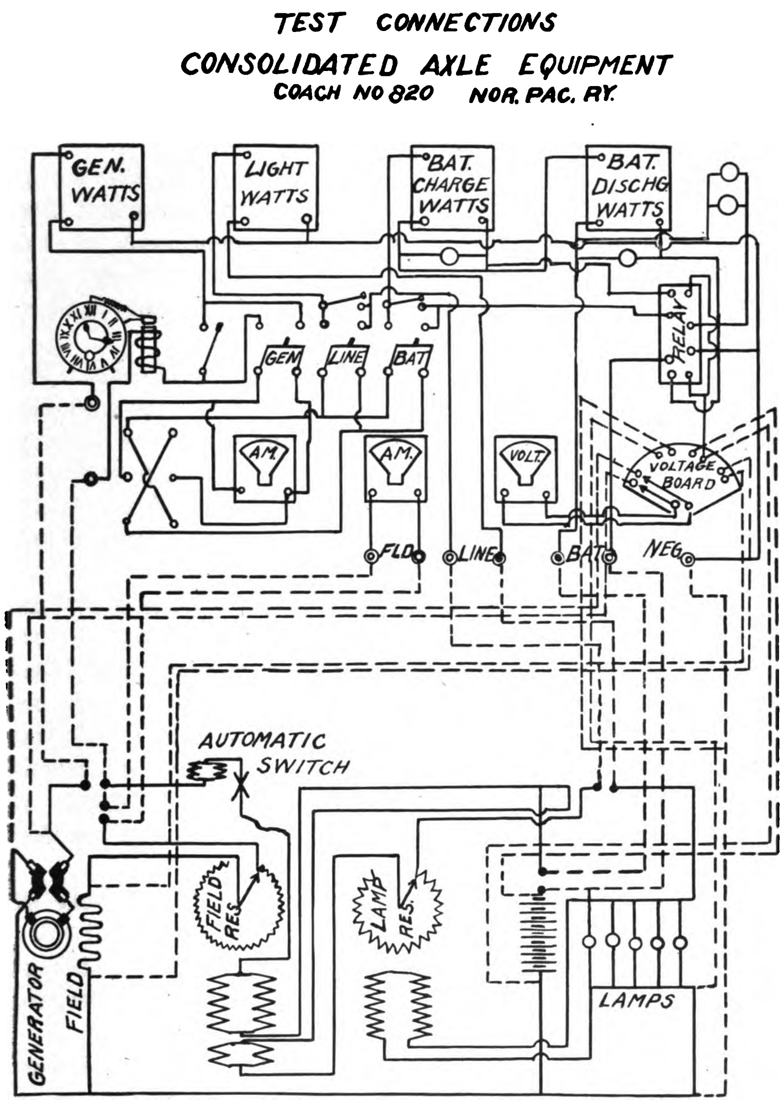


Plate XXI.—Test Connections, Consolidated Axle Equipment, Nor. Pac. Ry.

used corresponding to a No. 0, B. & S. gauge, so that the loss in test connections would be a minimum; these wires being passed under the seat and through a thin partition to the regulator closet.

The *test connections* are shown in Plate XXI. The lower half of the plate indicates the wiring connections of the axle equipment, while the upper half shows the test instruments and their connections, the dotted lines indicating the connections between the instruments and the axle equipment. The heavy dotted lines indicate No. 0, B. & S. gauge, while the fine dotted lines indicate voltage leads.

The reasons for taking the wattmeter data are obvious. The relation between the readings of the battery charge and discharge meters is of vital importance to the life of the battery, and the relation between the readings of the lamp and generator meters shows the total operating efficiency of the equipment. The meters employed were of the common integrating type, calibrated to the low voltage of this equipment.

The separation of the energy of battery charge from the energy of discharge presented a complex problem, as the current flows into the battery while the train is running and out of the battery while the train is stopped and lights are on. To separate these two values of energy, a polarized relay was constructed as illustrated in Plate XXII, to control the circuit relations of two wattmeters, one of which recorded the energy of battery charging and the other recorded the energy of discharging.

This polarized relay consists essentially of a heavy yoke of soft iron, A, see Plate XXII, wound with about 40 turns of No. 4 insulated copper wire through which the total battery current passes, thus creating one polarity while the battery is charging and the reverse polarity while the battery is discharging.

Suspended between the pole pieces of this yoke is one end of an electro-magnet, B, of constant polarity. It consists of a small strip of soft iron wound with 400 turns of No. 20 insulated copper wire. This coil is placed in series with two lamps directly across the battery, so that a constant magnetic flux is obtained.

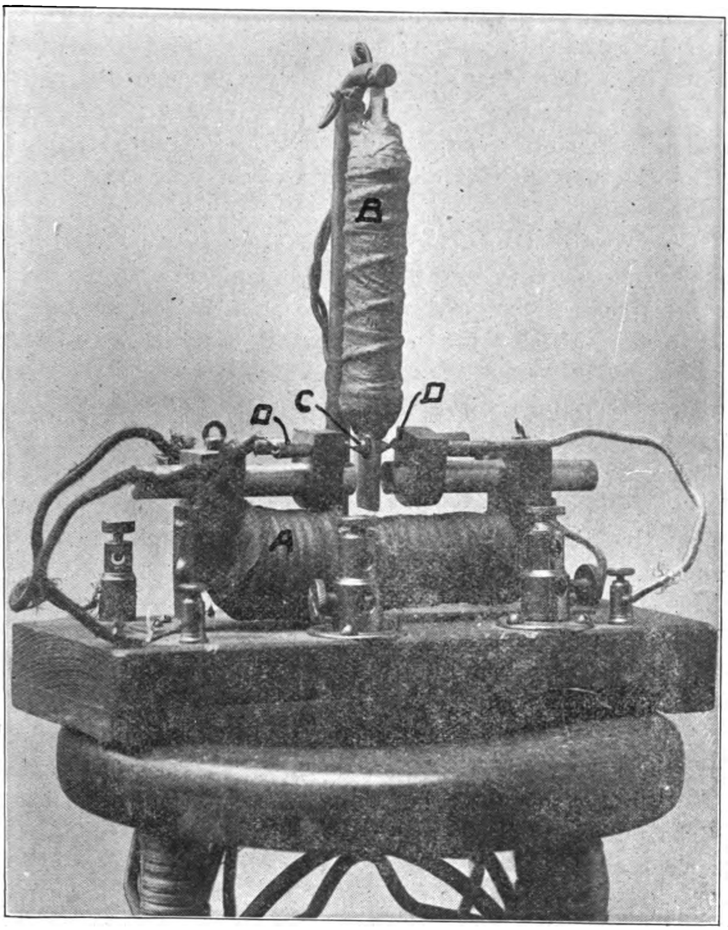


Plate XXII.—Polarized Relay.

Fitted on either side of this swinging bar of iron is an insulated brass button, C. When the battery current flows in, say, a charging direction, the reaction between the magnetism of the yoke and that of the swinging magnet draws the latter over till the brass button, C, makes contact between the two adjustable points DD, thus completing the circuit through the voltage coil of the wattmeter registering battery charge. The current coils of both wattmeters are placed in series with the heavy coil of the relay so that all battery current must pass through all three coils.

On reversal of the battery current, the polarity of the heavy yoke becomes reversed and the swinging magnet is drawn over to the other pole of the yoke, where the brass button on the other side of the swinging bar makes contact between the two contact points DD there located, thus completing the circuit through the voltage coil of the discharge wattmeter and causing it to record, the other wattmeter now being inoperative.

There are two pilot lights in the switchboard equipment, (see Plate XXI), which indicate when the corresponding wattmeter is operative, thus indicating whether or not the relay is working properly.

The other variable factor which it was necessary to determine was the total time of generator operation. A clock was fitted up on the principle of a stop watch operated by an electro-magnet in the generator circuit, as illustrated in Plate XXI. Obviously when the generator current flows through the solenoid, the keeper will be drawn down, thus stopping the clock, and when the generator is cut out of the circuit, the keeper will be pulled up by a spring and start the clock again, thus the clock records the time the generator is inoperative.

The *train speed* was determined by counting the rail clicks, since in case of a 30 foot rail the number of clicks in 20½ seconds gives directly the speed of the train in miles per hour. In case of 33 foot rails the clicks were counted for 22½ seconds, time being taken with a stop watch. This was found to be a very simple and sufficiently accurate method of taking speed readings.

Generator Efficiency. On arriving at St. Paul, a stray power

test of the generator was made by the rated motor method. The belt was removed from the generator and the generator was driven at various speeds with no load on the armature, by means of a small motor the losses of which had been previously measured. The input of the motor was then measured while driving the unloaded generator at various speeds and various excitations, from which the power necessary to supply these generator losses can be computed.

Knowing the stray power losses and armature resistance of the generator, the power absorbed from the driving belt or gearing by the generator while delivering any load to the lighting equipment can be computed; from which efficiency curves follow:

IMPORTANT RESULTS OF TEST

Total Time of Test	31 Hrs.
Generator Operating	23 ½ Hrs.
Generator Not Operating	7 ½ Hrs.
Lamps Lighted	13 ½ Hrs.
Total Generator Output	28.6 K. W. Hrs.
Total Lamp Consumption	14.6 K. W. Hrs.
Total Battery Charge	12.2 K. W. Hrs.
Total Battery Discharge	4.7 K. W. Hrs.
Average Generator Efficiency	80 %
Average Belt Efficiency (assumed)	97 %
Average Power absorbed from axle	2.08 H. P.

Total Efficiency for the Run —

$$\frac{\text{Lamp Cons. x Gen. Eff. x Belt Eff.}}{\text{Gen. Output}} = 39.6\ \%$$

DISCUSSION OF TEST

It was originally planned to make this test extend over the complete round trip of the car from St. Paul to Portland, Ore., and return, but the pole changer on the generator which was used, failed to work properly in the early part of the trip and was not repaired till the second day of the return trip, from which time the test was started.

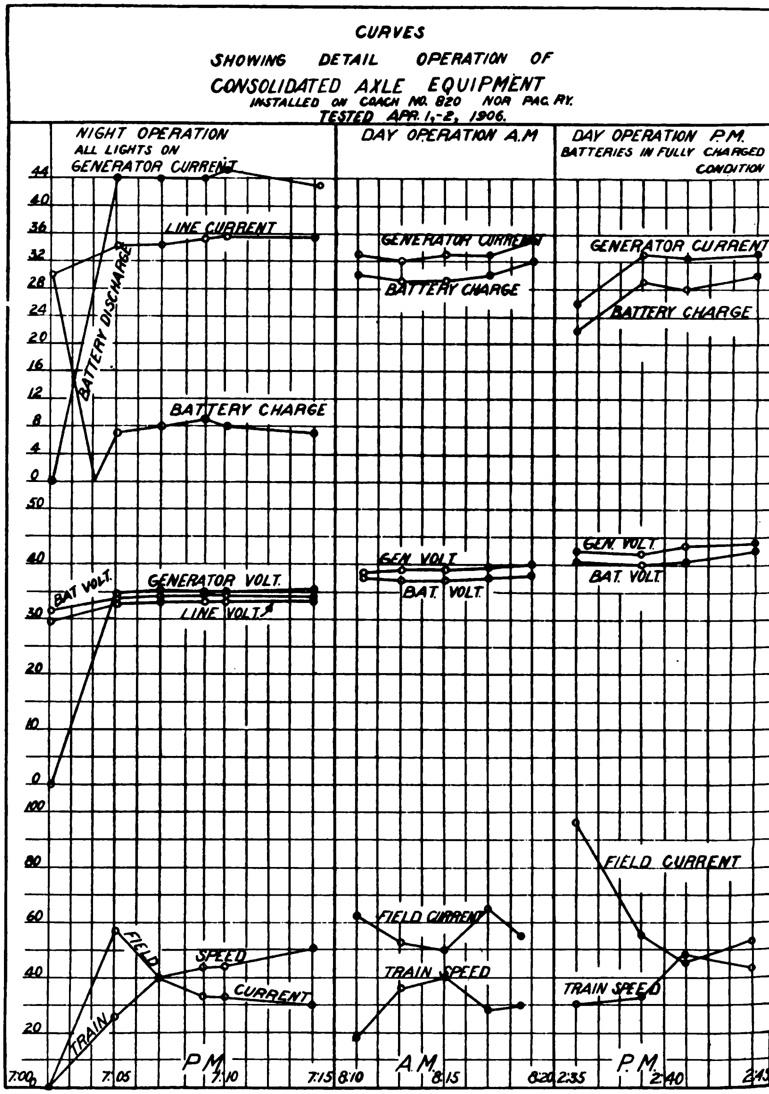


PLATE XXIII.—CURVES SHOWING DETAIL OPERATION OF CONSOLIDATED AXLE EQUIPMENT, NOR. PAC. RY.

It is not within the limits of this work to present in detail all the great mass of data taken in this test and accordingly only such data have been selected as are needed to typically illustrate the operation of this equipment, and these are plotted in the accompanying curves on Plates XXVIII and XXIV.

Referring to the tables of results on page 65, special attention should be called to the fact that the batteries are excessively overcharged, the ratio being 4.7 K. W. Hr. discharge and 12.2 K. W. Hr. charge during 13½ hrs. of night run and 17½ hrs. of day run. This might be remedied by changing the regulator setting so as to reduce the generator current by about five amperes, which would have given about 9.4 K. W. Hr. charge with the 4.7 K. W. Hr. discharge. This amount of charging would doubtless be ample to care for battery efficiency and also to make recovery from any heavy discharges due to delays of the train.

This setting of the regulator would give a generator output of 39 amperes when all lights are on instead of the 44 amperes of the test. (See Plate XXIII.)

The excessive overcharge of the batteries is shown plainly by the voltage readings of the battery taken throughout the day, plotted on Plate XXIV. It is seen that by 12:30 P. M. the voltage had risen to its maximum of about 42 volts indicating charged condition of the battery and it remained at that value throughout all the rest of the charging period, which continues all afternoon and till the lights are turned on at 6:30 P. M.

Such excessive overcharging causes rapid destruction of the battery plates and should be prevented.

Referring to the curves on Plate XXIII it is to be noted:

1. During night operation the generator charges the batteries with about 8 amperes as well as lighting the lights.

2. Field current varies inversely with the train speed.

3. Lamp regulation is fair, holding the lamp voltage between 29 to 33 volts but not so good as was expected from the special lamp regulator installed on this equipment.

4. Generator current regulation is fairly constant for wide variations of train speed.

Referring to the day operation in the second and third columns of this same plate, it is noted:

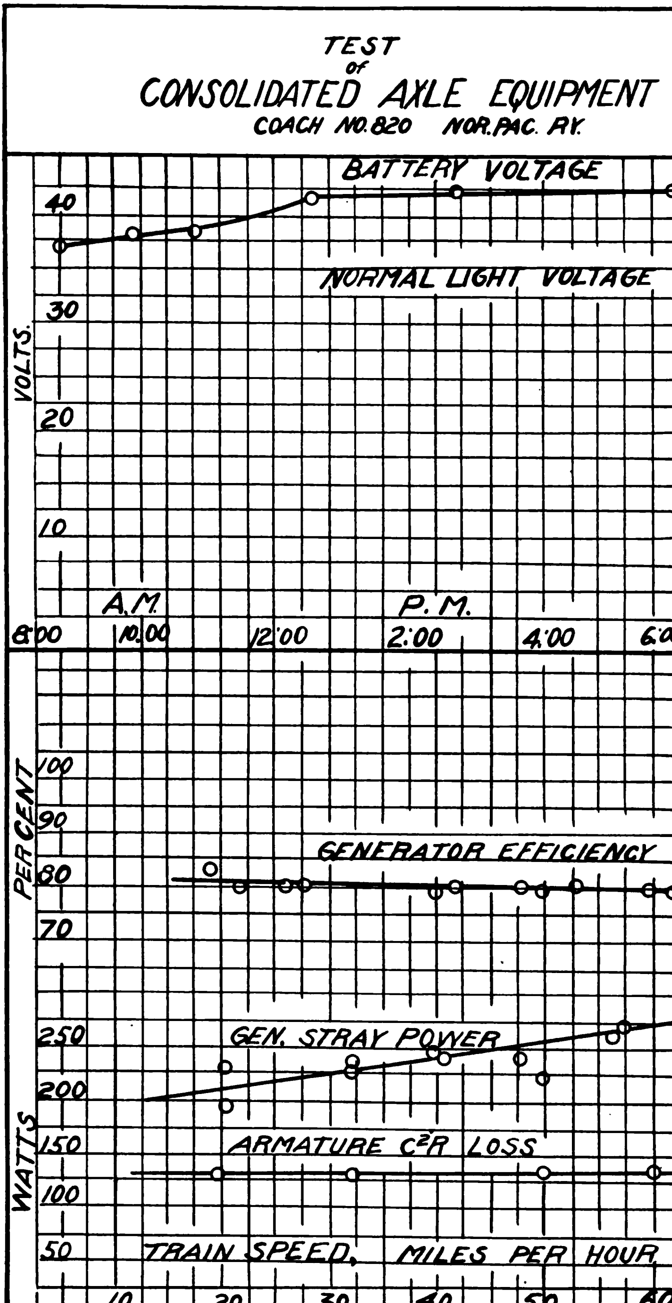


PLATE XXIV.—SHOWING GENERATOR LOSSES AND EFFICIENCY AND ILLUSTRATING THE BATTERY OVERCHARGE.

1. Generator current has dropped to 33 amperes but stays practically constant at that point for both A. M. and P. M.

2. Generator voltage rises directly with the battery voltage, proving the point that the equipment regulates for constant current output irrespective of the voltage required.

A voltmeter test of the regulation afforded by this equipment was made on a later run, after the regulator had been carefully adjusted but the variation of voltage remained about 10 per cent.[6]

Test of Consolidated Axle Equipment

Observation Car "Dynamene,"

C., B. & Q. Ry.

This equipment is one made by the Consolidated Company at an earlier date, and the Kennedy regulator as described on page 56 was developed as an improvement over this type.

This equipment has substantially the same principles of control as the Kennedy regulator previously described, except in regard to regulation of lamp voltage.

It consists essentially of a generator, pole changer, automatic switch, regulator, storage battery auxiliary, and lamps and switches within the car.

The generator and pole changer are identical with those described on page 55 and will not be considered further at this point.

The regulator consists essentially of a large controlling solenoid A (See Plate XXVI), an automatic switch C operated by the electro-magnets B and D, an operating motor E, a field rheostat the contact points of which are shown at R, and a lamp circuit rheostat at M.

As the train speed reaches the value at which the generator voltage is equal to that of the battery, the magnetism created

[6] For complete data of this test refer to the graduating thesis of O. B. Cade and A. J. Walsh, University of Wisconsin, 1906.

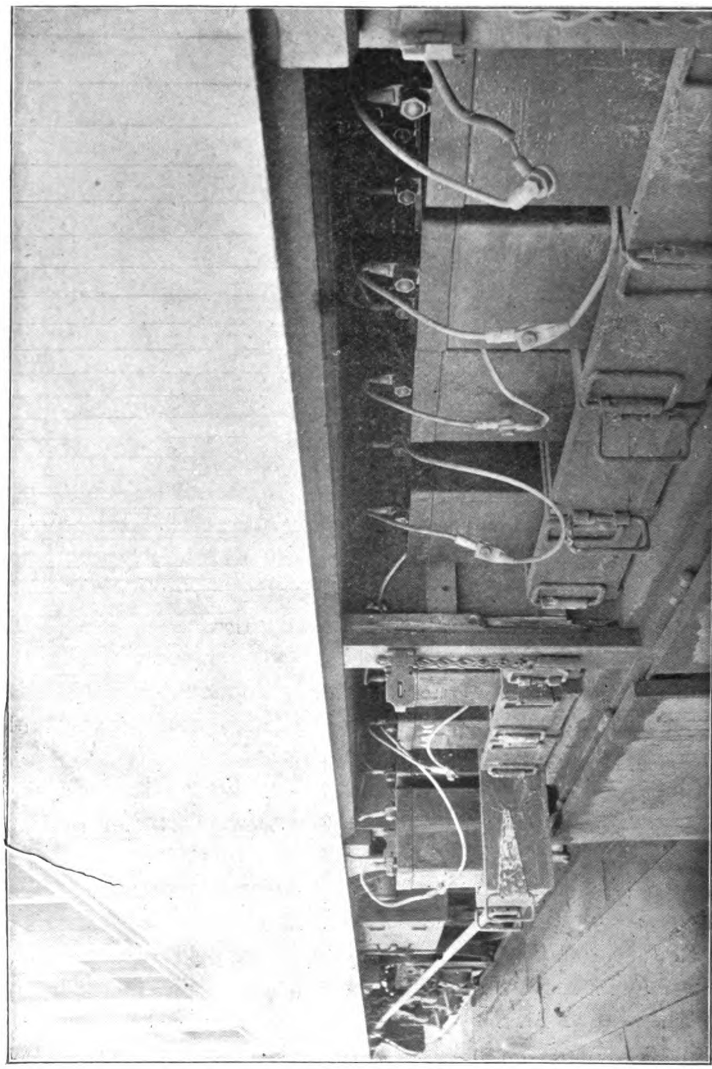


PLATE XXV.—SHOWING LOCATION OF BATTERY.

in the two shunt coils D, which are mounted on a movable arm, will be such as to draw themselves up to the magnet coils B, thus closing the switch C connecting the generator in parallel with the battery and lights.

As the generator speed becomes higher, its voltage tends to rise above that of the batteries and the generator assumes its load. The generator current flowing through the large solenoid A then affects an iron plunger J in direct proportion to current flowing, this magnetic pull being counterbalanced by an adjustable spring K, the adjustment of which determines the value of the normal generator current.

The motion of this magnetically controlled plunger is transferred by the lever arms O to the control of two little ratchet dogs P which are being moved back and forth continually by an eccentric on the motor worm-wheel F. These little ratchet dogs engage with two ratchet wheels, one of which is right handed and the other of which is left handed, shown at O in Plate XXVI, these wheels being mounted rigidly on the adjustable field rheostat arm R. When regulation of the voltage is necessary, one of the ratchet dogs P is allowed to engage with its corresponding ratchet wheel G and cause it to be rotated, moving the field rheostat arm R to such a point as to produce the desired voltage. It is obvious that only one of these motor driven dogs is allowed to engage with its corresponding wheel at one time.

A rheostat at M is inserted in the lamp circuit when the generator becomes operative, to compensate for the difference between battery charging voltage and battery discharging voltage, thus maintaining a reasonably constant voltage on the lamps. This is effected by the rheostat arm and resistence contact points at M being operated by a cam and follower mounted on the ratchet wheel G of such construction that it causes the resistance to be all inserted at the first quarter turn of the ratchet wheel.

In regard to the operation of the automatic switch (B, C, D), after the magnetism of the generator shunt coils becomes of sufficient intensity in the coils DD, they draw themselves up to the coils BB, thereby closing the generator switch C. The coils

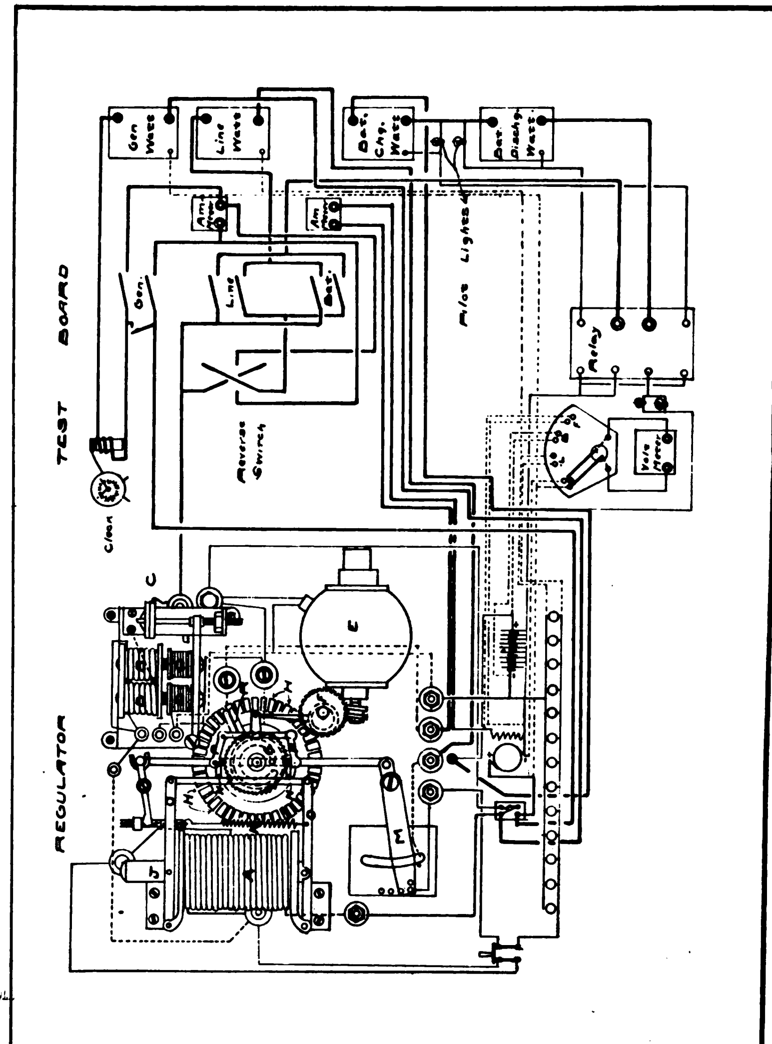


PLATE XXVI.—REGULATOR (OLD TYPE) OF CONSOLIDATED AXLE EQUIPMENT.

BB are wound with heavy wire and all the generator current passes through them so that on closing the generator switch C the generator current flowing through them will intensify the magnetism of coils DD, and insure good contact at C.

The *battery* consists of a set of 16–240 ampere hour cells of the type 13–E, made by the Electric Storage Battery Co., which are located beneath the car as illustrated in Plate XXV. The jars used are of reinforced hard rubber and are set in wooden trays, two jars in a tray.

METHOD OF TEST

The method of making the test was almost identical with that used in the previous tests and described on page 60. Several changes, however, were necessary in making test connections, (as shown by Plate XXVI).

The car upon which the equipment was operating was a Pullman sleeper and observation car, so there was no accommodating space in which to lay any bulky switchboard as in previous tests. The four wattmeters (shown in Plate XXVI) were placed on the platform over the steps in the vestibule, and the remainder of the test apparatus was located within the regulator locker.

The generator was identical with that tested on the Northern Pacific Ry. so a duplicate efficiency test was not made, but reference can be made to the curve on Plate XXIV in connection with this test. The efficiency itself is slightly different due to the difference in output.

IMPORTANT RESULTS OF TEST

Farnsworth Consolidated Axle Equipment on Observation Car Dynamene—Chicago to Kansas City.

Total time of trip	14 hrs. 10 min.
Total time Generator operating	11 hrs. 35 min.
Total time Generator not operating	2 hrs. 35 min.
Total time Stops	1 hrs. 22 min.
Total time Generator running dead	1 hrs. 13 min.
Total time Lights on Batteries	2 hrs. 35 min.

Total Generator Output	19.6 K. W. Hr.
Total Lamp Consumption	8.38 K. W. Hr.
Total Battery Charge	7.9 K. W. Hr.
Total Battery Discharge	1.86 K. W. Hr.

Kansas City to Chicago.

Total time of trip	13 hrs. 42 min.
Total time Generator operating	10 hrs. 55 min.
Total time Generator not operating	2 hrs. 47 min.
Total time of stops	1 hrs. 24 min.
Total time Generator running dead	1 hrs. 23 min.
Total time Lights on Batteries	2 hrs. 47 min.
Total Generator Output	19.2 K. W. Hr.
Total Lamp Consumption	7.28 K. W. Hr.
Total Battery Charge	7.03 K. W. Hr.
Total Battery Discharge	1.87 K. W. Hr.

Above readings are corrected for loss in test connections.

Average Generator Eff. = 80%.

Total Efficiency of Equipment—Kansas City to Chicago =

$$\frac{\text{Lamp Cons. x Gen. Eff. x Belt Eff.}}{\text{Gen. Output}} = 29.5\%$$

The average battery discharge equals 1.86 K. W. Hr.

In order to compensate for battery efficiency of 50%, there should have been 3.7 K. W. Hr. charge. Instead of this it is seen that there was about 7.5 K. W. Hr. (av. of two trips). This leaves 3.8 K. W. Hr. of destructive overcharge which might be eliminated.

3.8 K. W. Hr. at 40 volts = 95. amp. hrs.

Since the generator was operating for about 11 hrs. this would represent an excess of 8.6 amperes in the regulator setting, and the generator might be set at about 33½ amperes with all lamps on instead of 42 amperes as at time of test.

DISCUSSION OF RESULTS

The most striking of the results observed, and one which is of critical importance to the life of the equipment, is that the

batteries are tremendously overcharged on both outgoing and return trips, as is shown by a comparison of the values of energies of battery charge and battery discharge as shown on page 74. The cause of this is primarily due to the fact that the regulator was set too high, a fact which seems to be universally true in all constant current regulation. This is necessary to a certain degree to be on the "safe side" in maintaining the lights, but an extreme overcharge such as is here experienced should not be allowed as it is sure to cause the early destruction of the battery.

The results of this test again illustrate that objectionable part of axle operation which is inherent in the arrangements affording constant current regulation. It is noted from the description on page 71 that the iron plunger J which controls the operation of the field rheostat is held in equilibrium between the magnetic pull of the solenoid and the tension in the spring K. Now the magnetic pull of the coil A is proportional to the current flowing through that coil and is no function of the generator voltage so that the regulation will be such as will maintain constant current output of the generator irrespective of its voltage. This is a great disadvantage from a battery standpoint, in that after the batteries have become fully charged they still continue to be overcharged at the normal rate so long as the generator is operating.

Attention should be called to the fact that the total trip efficiency of the outfit is only 29.5%. This is due largely to the fact that the batteries are greatly overcharged, thus wasting a large amount of power, and it is also due to a large line loss, which is shown by the generator output being considerably higher than the sum of the lamp consumption + battery charge—battery discharge. This indicates a very high line loss and is substantiated by a reference to Plate XXVII which shows an average line loss of about 13%. The values given under wattmeter readings on page 74 have been duly corrected for the instrumental errors, so that the readings are true values. It should be noted that the voltage connections of the wattmeters were provided by special leads from the generator, line, and battery so that the readings are not vitiated by the line loss.

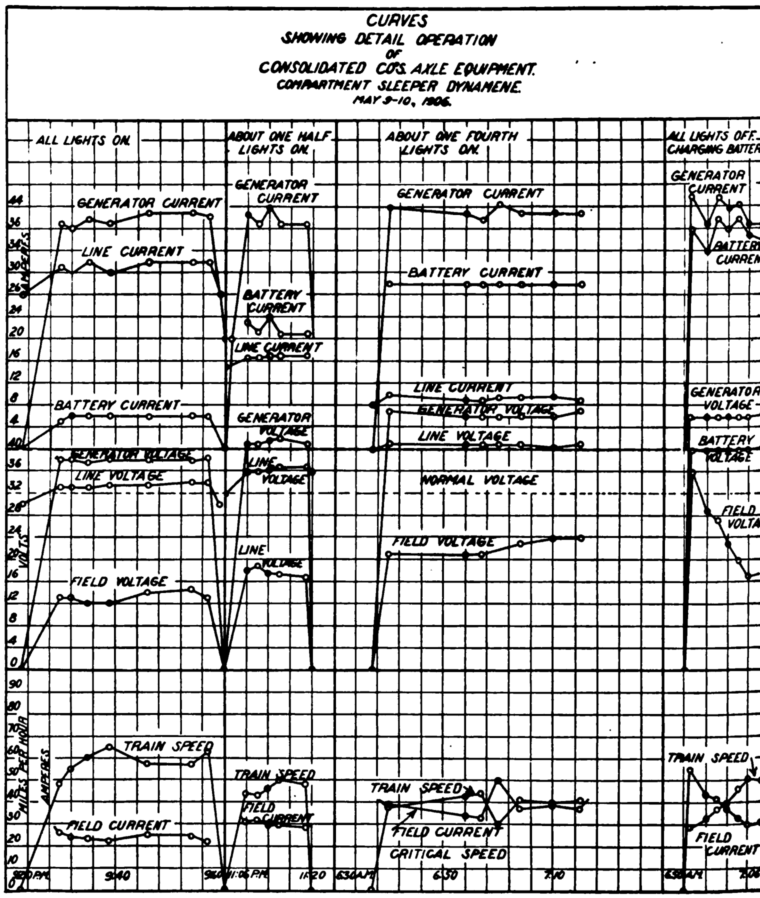


PLATE XXVII.—CURVES SHOWING DETAIL OPERATION OF CONSOLIDATED AXLE EQUIPMENT, COMPARTMENT SLEEPER DYNAMENE.

In discussion of the detail curves of operation, Plate XXVII, there are many important features to be noted which are typical in the operation of this equipment.

It should be first noted that these curves are in four different sets: one under full load condition of lighting, another with only half the lights on, a third with only one-fourth the lights burning and the fourth set of curves indicating the detail operation while charging batteries with no lights on.

The uppermost curve shows that the generator current remained practically constant at all times whether all lights are on, one-fourth lights on, or no lights on. This substantiates the statement that the regulator is one for constant current irrespective of the generator voltage.

Another point of particular interest in the curves is the variation in lamp voltage as the line current decreases and the batteries become charged. It is also noted that the lamp voltage varies directly with and is almost equal to the battery charging voltage, thus indicating the undesirability of this method of inserting the rheostat.

Another point of technical interest is shown by the two lower curves, in the inverse variation of field current and train speed, an increase in train speed being always accompanied by a decrease in field current and vice versa.[7]

Test of Newbold Axle Equipment

Northern Pacific Ry.

DESCRIPTION OF APPARATUS

The axle driven equipment of the Newbold type is based on essentially the same principles as certain earlier devices, the difference in design being of a mechanical nature largely. It is of the class that controls by varying field resistance.

The essential parts are, a generator belted to a large axle pulley, a storage battery to assume the load of lighting while the generator is inoperative, an automatic switch to close the

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[7] For the complete data of this test refer to the graduating thesis of A. U. Hoefer and Edgar Kearney, University of Wisconsin, 1906.

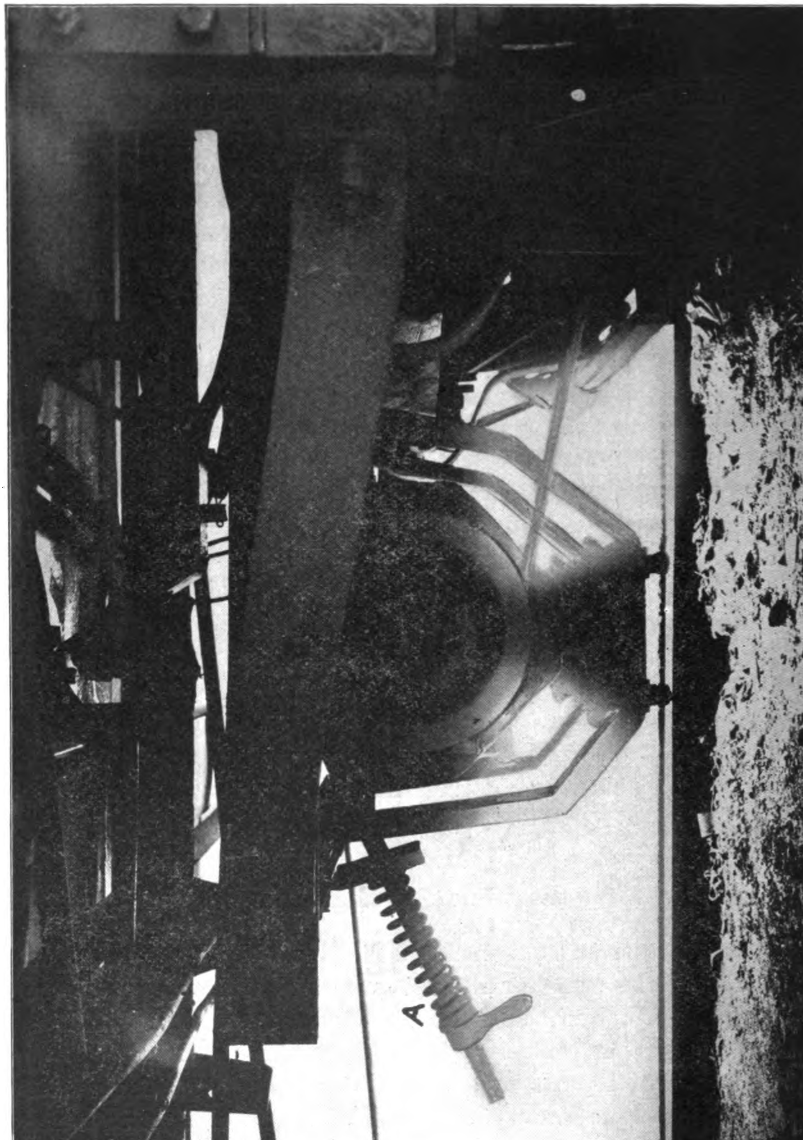

PLATE XXVIII.—GENERATOR OF NEWBOLD AXLE EQUIPMENT.

generator circuit when the critical speed is reached, a regulator to maintain the generator voltage constant by adjusting a suitable field rheostat, and a pole changer to provide proper polarity of the generator to the batteries independent of the direction of rotation of the generator.

The *generator* is of a 60 volt, 40 amp., 4 pole, direct current type. It is suspended from the outside of the front end of the truck sill, as per Plate XXVIII, and is pivoted on a rocker roller that is set on the supporting frame parallel to the car axle, thus allowing the adjustable spring A to maintain the proper belt tension. The belt is a 4 ply canvass rubber belt 4″ wide and passes over and under the truck sill as shown.

Oil rings and a quantity of oil sufficient for several months lubrication are supplied.

The generator is encased in a dust proof casing which is supplied with a single large hand hole which gives access to the brushes for repairs and inspection. This is provided with a felt lined cover which renders it dust proof. The case is built so that the end may be easily removed and the armature be readily taken out. The generator having four poles, the current is taken from the two adjacent brushes on the forward side of the commutator, thus making the brushes more accessible.

The *pole changer* is that part of the mechanism which provides proper polarity to the circuit whichever the direction of motion of the car may be. A worm is fastened to the armature shaft and engages a worm wheel. To this wheel is fastened a friction-strap clutch that grips a four-pole switch in case the motion of the train be reversed and drags it around till it makes contact in the reverse manner, then at this point a dog trips the friction-strap clutch and the worm wheel is allowed to turn thereafter without the friction of the clutch. On reversal of the motion of the car, the switch is reversed, thus keeping proper polarity in the circuit whatever the direction of train motion. A few sheets of hard steel are supplied in building up the pole pieces of the field magnets to insure proper magnetic polarity of the fields.

The function of the *automatic switch* is to close the generator

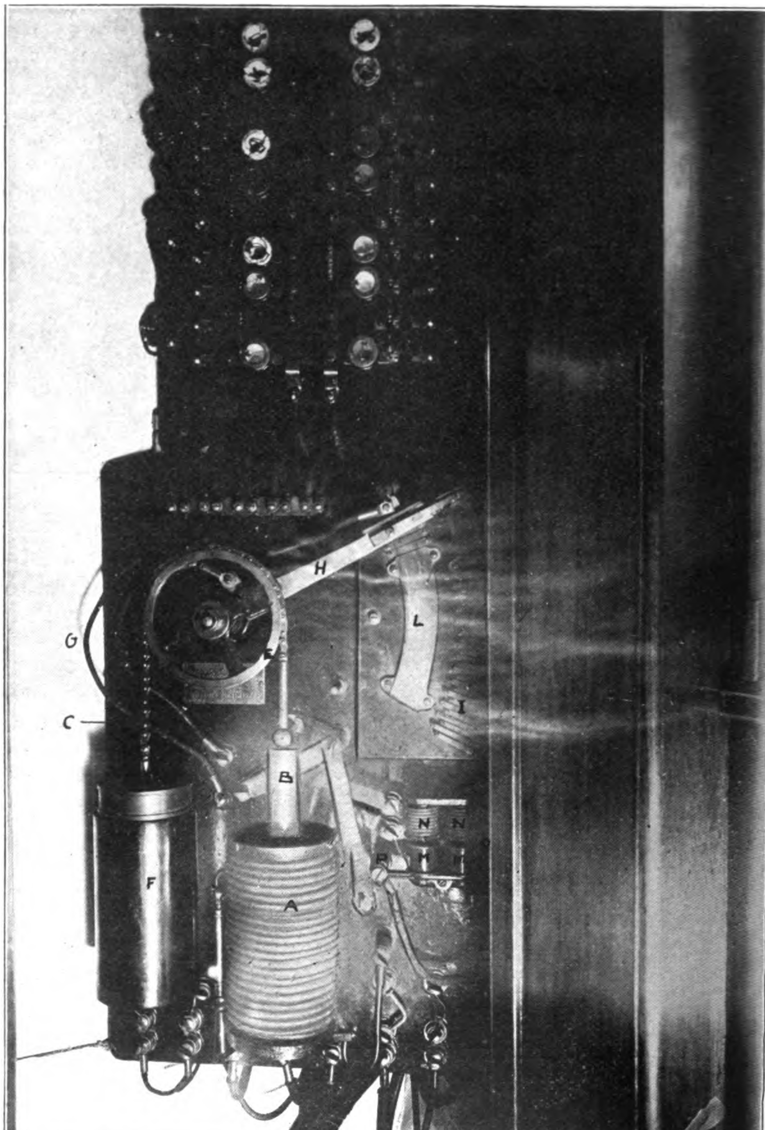

PLATE XXIX.—REGULATOR OF NEWBOLD AXLE EQUIPMENT.

circuit when the critical speed is attained. A coil of very fine wire, M, Plate, XXIX, is mounted on a lever arm pivoted at P, and is connected directly across the terminals of the generator, the adjustment being such that when the generator attains a voltage equal to that of the battery, the magnetism developed in this coil will be of sufficient strength to draw up the lever arm, thus closing the switch at O. When the generator, now on the line, begins to assume the load, all the current passes through the series coil N and increases the magnetic pull of the shunt coil M, insuring good contact in the automatic switch O.

In opening the automatic switch, the series coil has an important function which is not generally recognized. For simplicity in explanation of this, consider all lights off, *i. e.*, the generator furnishing current for charging battery in the day time. When the speed of the train is above the critical value the generator is charging the battery and the current passing through the series coil N intensifies the magnetic pull of the shunt coil M. Now if the speed decreases, the generator voltage drops till it is equal to that of the battery provided the speed decreases sufficiently and the current flowing will be zero, but still the automatic switch will stay closed due to the magnetic pull of the shunt coil M. But, now, as soon as the generator voltage drops a little below that of the battery there will be a current flow in the reverse direction through the series coil N, thus creating a magnetic flux in it in opposition to that of M which will accelerate the opening of the switch.

It is obvious that if the shunt coil alone were used to operate the automatic switch, the battery pressure would tend to hold it closed even far below the critical speed, since the battery, generator, and shunt coil are all in parallel when the switch is closed, and an injurious battery short-circuit would occur, or, if the automatic switch did open, it would do so under heavy arcing due to the battery discharge current.

The function of the *regulator* is to maintain proper voltage in the system. In this equipment it is properly called the "Gravity Regulator" as it depends on balancing the pull of gravity on a shot bucket on one side against the pull on an electric magnetic solenoid on the other. This is accomplished by the appar-

atus illustrated in Plate XXIX. The generator current energizes the large coil A which actuates the plunger B, this being suspended on a flexible chain C which passes over a wheel E mounted on ball bearings and fastened to the piston of the dashpot F. The piston of this dashpot is loaded with shot to an amount which is adjusted to balance the pull on the core of the rated generator current flowing through the coil A.

From this balancing wheel is extended a long arm H carrying two contact shoes, one of which carries the field current and engages with the bars I of the field rheostat and the other G, which carries the lamp current and makes contact with the corresponding bars of the lamp rheostat which are shown above L.

The lamp rheostat is so placed that its contact points are all cut into circuit when the lever arm first moves down. The function of this lamp rheostat is to compensate for the rise in voltage of the generator over that of the battery in assuming the load from the battery.

In regard to this dashpot piston loaded with shot,—there are two compartments to it, one loaded heavily with shot and one with no shot in it at all. These are so placed that when the arm H is in the zero position the heavier shot piston is not supported by the chain C but rests on the top edge of the dashpot F, so when the generator circuit is first closed a slight current in the coil A will overcome the weight of the lighter piston, thus drawing the plunger B into the coil A and causing the arm H to move downward until the lighter piston comes in contact with the heavy one above it, thereby cutting in all the resistance of the lamp rheostat and the first few sections of the field rheostat. Now, as the speed of the generator increases and the generator assumes more load, the magnetic pull of the solenoid A increases until it reaches a value sufficient to overbalance the weight of both pistons in the dashpot F, whereupon the arm H is drawn downward cutting in the field rheostat I as may be needed.

Another function of this dashpot is to render the operation of the plunger and lever arm rather sluggish. This is due to the fact that the dashpot piston is made to fit closely to its cylinder and on raising or lowering the piston, air is forced in or out of

a tiny hole in the bottom of the cylinder. This is essential in protecting the equipment from accident and abuse, for if, due to some poor connection in the circuit the generator current should come and go, or if a blown main fuse should be replaced while running at a high speed, a great "hunting effect" would take place if the dashpot were omitted, that is, the generator voltage and current would surge up and down between wide limits, all due to the fact that the field magnets do not respond immediately to a change in field current.

The battery consists of a set of 32 cells of type 13–E of 240 ampere hour capacity, made by the Electric Storage Battery Co., located beneath the car in the same manner as shown in Plate XXV.

The fundamental principle at the basis of this regulator is that as the generator pressure tends to rise the battery current input rises almost proportionally to the *increase* in voltage. This energizes the coil A more strongly, thus pulling the plunger down farther and cutting in more field resistance I till normal conditions are restored and the generator current returns to normal value. On a decrease of speed occurring the reverse operation occurs, the lever arm H being gradually lifted by the weights in F overcoming the decreasing pull of the solenoid, till the pressure is raised to normal value, this continuing till the critical speed is reached, when, on a slight further decrease of speed, the automatic switch opens and the lights are fed from the battery.

METHOD OF TEST

The method of test was essentially the same as that described on page 60, but is illustrated more in detail by Plate XXX. The lower half of the plate indicates the equipment as normally installed, the upper half shows the testing instruments, while the dotted lines indicate the wiring between the instruments and the equipment, the heavy dotted lines indicating wire of No. O. B. & S. gauge, while the fine dotted lines indicate where voltage leads were used.

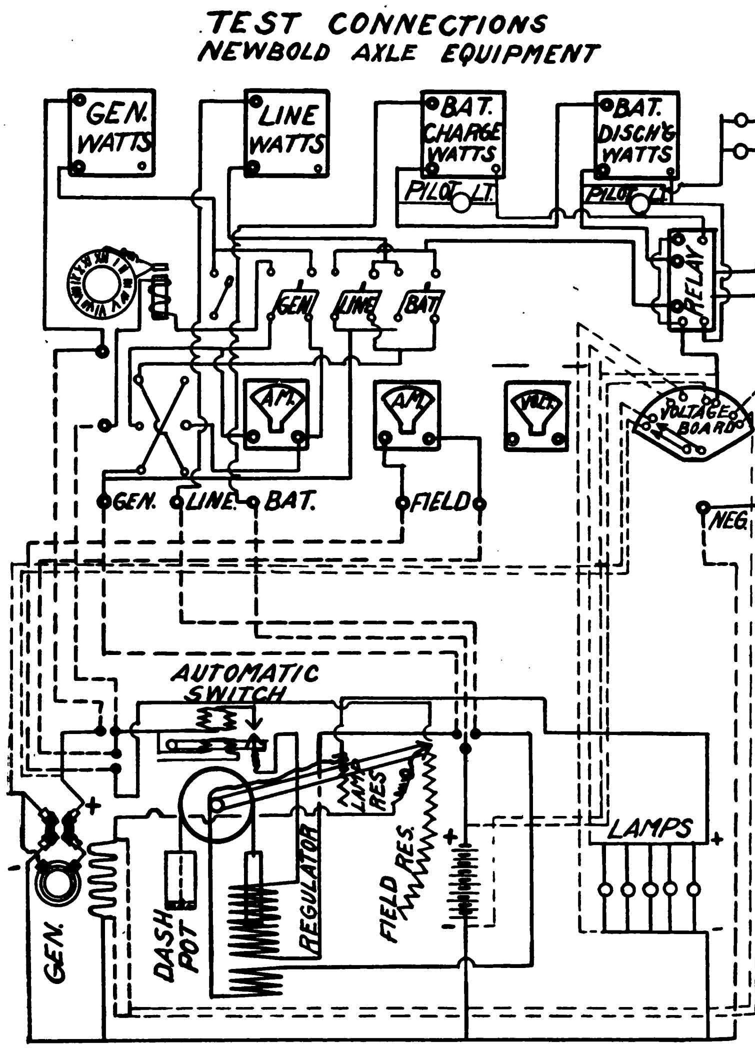

PLATE XXX.—TEST CONNECTIONS, NEWBOLD AXLE EQUIPMENT.

RESULTS OF TEST

St. Paul to Portland. March 24 to 28, 1906.

Duration of test	74	Hrs.
Generator Operating	53	Hrs.
Generator not operating	21	Hrs.
Lamps Lighted	35	Hrs.
Battery Charge	39	Hrs.
Total Generator Output	105	K. W. Hr.
Total Lamp Consumption	54.3	K. W. Hr.
Total Battery Charge	56	K. W. Hr.
Total Battery Discharge	9.7	K. W. Hr.
Average Generator Efficiency	80%	

Power absorbed from axle at 60 mi. per hr. = 3.4 H. P.

Total efficiency of run =

$$\frac{\text{Lamp Cons. x Gen. Eff. x Belt Eff.}}{\text{Gen. Output}} = \frac{54.3 \text{ x } 80\% \text{ x } 97\%}{105}$$

= 40% total efficiency of run.

Belt loss is assumed as 3%.

Portland to St. Paul.

Duration of test	66	Hrs.
Generator Operating	51	Hrs.
Generator not operating	15	Hrs.
All Lamps Lighted	34	Hrs.
Battery Charging	32	Hrs.
Total Generator Output	95.5	K. W. Hr.
Total Lamp Consumption	55.7	K. W. Hr.
Total Battery Charge	42.5	K. W. Hr.
Total Battery Discharge	10.7	K. W. Hr.
Average Generator Efficiency	80%	

Power absorbed from axle at 60 mi. per hr. = 3.4 H. P.

Total efficiency of run =

$$\frac{\text{Lamp Cons. x Gen. Eff. x Belt Eff.}}{\text{Gen. Output}} = \frac{55.7 \text{ x } 80\% \text{ x } 97\%}{95.5}$$

= 45.3% total efficiency of run.

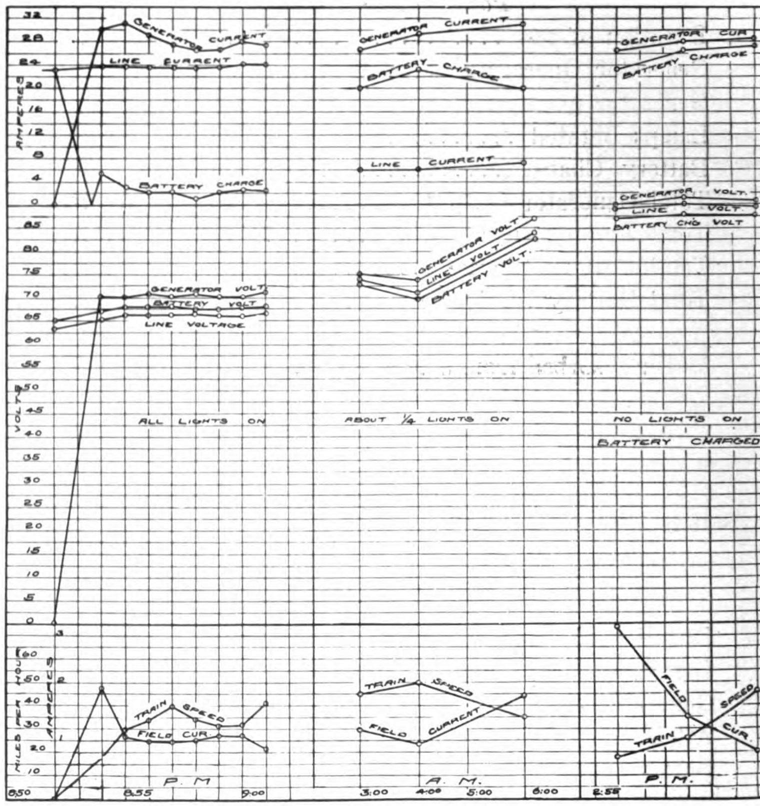

Plate XXXI.—Showing Detail Operation of Newbold Axle Equipment on Coach No. 962, Nor. Pac. Ry.

The regulator might safely be adjusted to bring the generator current to 20 amperes instead of 28 amperes, with resulting saving of battery depreciation and economy in power.

DISCUSSION OF TEST

The most striking result of the test and one of critical importance to the life of the equipment is the fact that the batteries are destructively overcharged as shown by a comparison of the wattmeter readings of battery charge, 56 K. W. Hr., page 85, and battery discharge, 9.7 K. W. Hr., also by a comparison of total generator output 105 K. W. Hr. and total lamp consumption 54.3 K. W. Hr. This is due to the fact that the regulator is set so undesirably high.

Another point of special note is that the lamp voltage follows directly the rise in battery voltage as shown by a comparison of the voltage curves in the three columns; that in the first column representing normal operation at night with all the lamps lighted; that in the second column representing the rise in battery voltage from normal to the nearly charged condition of the battery at 5:45 A. M.; while that in the third column represents an overcharging condition. It is to be observed that any lights in use during the time represented by the conditions indicated by the second column receive this enormous rise in voltage and are accordingly rapidly destroyed. It should also be noted that, had all the lights been left lighted all night, this great rise in voltage would not occur, but the operation would have continued practically constant following the conditions represented by column 1.

Incidentally it may be observed that the field current of the generator varies inversely with the train speed.

Referring to curves on Plate XXXII, the curve of battery voltage indicates the condition of battery charge, and shows that by noon the batteries had become fully charged and that all the rest of the day they were destructively overcharged. This again substantiates the point indicated earlier, that the regulator was not adjusted for the most economical conditions of use. An overcharge of a half hour occasionally is a good thing to keep the

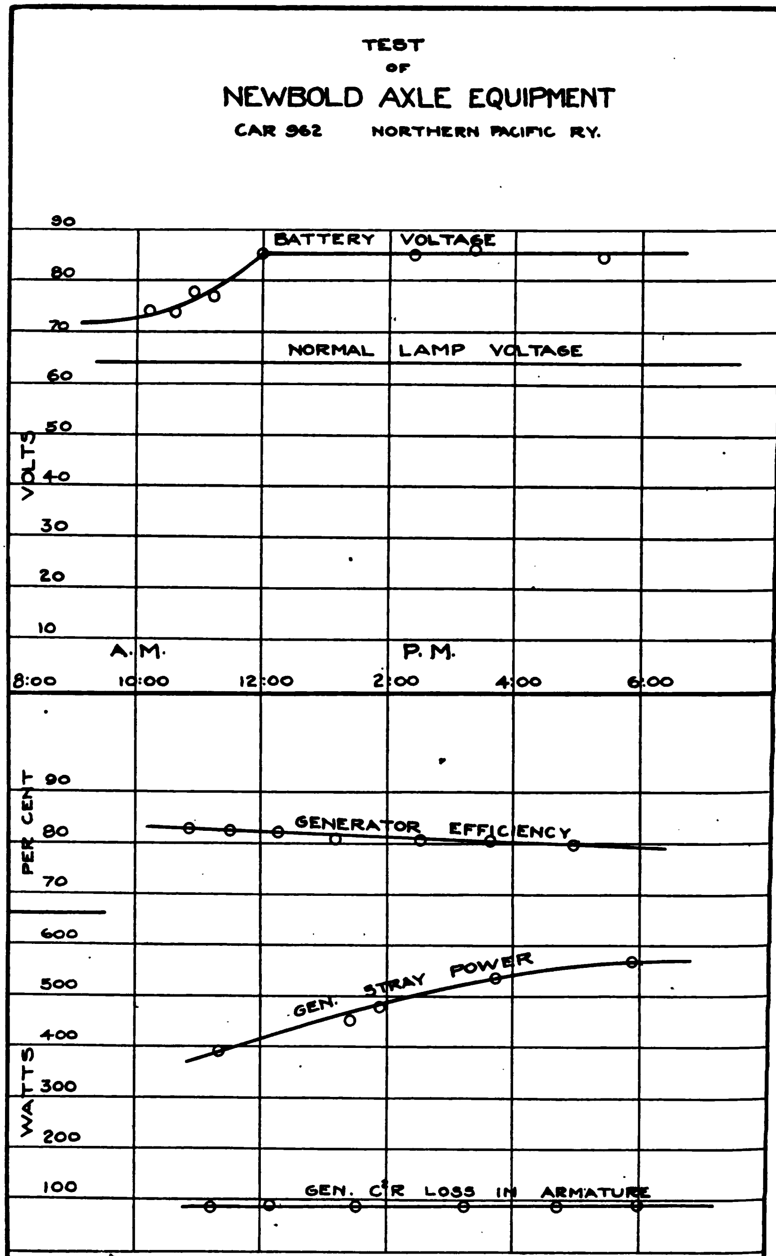

PLATE XXXII.—TEST OF NEWBOLD AXLE EQUIPMENT, NOR. PAC. RY.

battery from becoming sulphated, but an overcharge of six hours every day at the normal rate is sure to cause complete and rapid destruction of the battery besides a large waste of power.[8]

TEST OF NEWBOLD AXLE EQUIPMENT

ON DINING CAR "HANNIBAL,"

C. B. & Q. RY.

The equipment in this test is on exactly the same principles of operation and design as the Newbold equipment tested on the Northern Pacific Railway and described on page 77, except for the fact that this equipment operates at 30 volts instead of 60 as was the case on the other equipment.

This equipment is of special interest in that it operates under exceedingly heavy duty, the normal lamp current being 75 amperes, and moreover it is operated on a short run where it must maintain itself under markedly different conditions at the different seasons of the year; that is, in the winter months it must maintain the lights lighted not only on the run but must furnish light for about two hours while standing in the yards at Chicago, and on the return trip must maintain lights while on the run and also for an hour while standing in the yards. On the other hand, in the summer months the lights are turned on for only about an hour and a half altogether.

The car was put into service in March, only about two months before the test was made, so that it had not experienced any winter service at that time.

It operates on a short run of about 100 miles from Chicago to Mendota, Ill., leaving Chicago at 6:10 P. M. and arriving at Mendota at 8:05 P. M., where it remains till 5:56 A. M. the next morning, when it returns to Chicago, arriving there at 8:00 A. M.

METHOD OF TEST

The same methods were employed in this test as were used in all the other tests of axle equipment, and they are discussed on

[8] For the complete data of this test refer to the graduating thesis of O. B. Cade and A. J. Walsh, University of Wisconsin, 1906.

PLATE XXXIII.—INTERIOR OF DINING CAR "HANNIBAL."

page 60 so will not be repeated here, except to indicate the location of the instruments. There was of course no available room within the car (which is a dining car) for the location of a test board, except a very small space in the regulator locker. Accordingly, the switches, voltmeters, and ammeters were placed in this locker, while the larger instruments, such as the wattmeters, relay and clock, were placed in the vestibule, and all wiring connections were made to them as shown in Plate XXX. The lower half of the plate indicates the wiring connections of the axle equipment while the upper half shows the test instruments, the dotted lines indicating the connections between the instruments and the axle equipment. The heavy lines indicate No. 4 wires while the finer lines indicate voltage leads. It should be noted that special voltage leads were run from the generator, line, battery and field winding.

In testing this equipment, three round trips were made, two under normal operating conditions of that date, May 15, which is by the way near the summer solstice, and one trip under such conditions artificially produced as would be probably experienced in the winter months, that of receiving a discharge at half load for two hours in the yards before leaving in the evening and for one hour on returning in the morning.

RESULTS OF TEST

Trip 1.

Duration of test (round trip)	3 hr. 59 min.
Generator operating	3 hr. 22 min.
Total generator output	8.64 K. W. Hr.
Total lamp consumption	5.24 K. W. Hr.
Total battery charge	3.82 K. W. Hr.
Total battery discharge	1.2 K. W. Hr.

Trip 2.

Duration of test	3 hr. 59 min.
General operating	3 hr. 15 min.
Total generator output	9.36 K. W. Hr.
Total lamp consumption	6.26 K. W. Hr.
Total battery charge	3.86 K. W. Hr.
Total battery discharge	1.6 K. W. Hr.

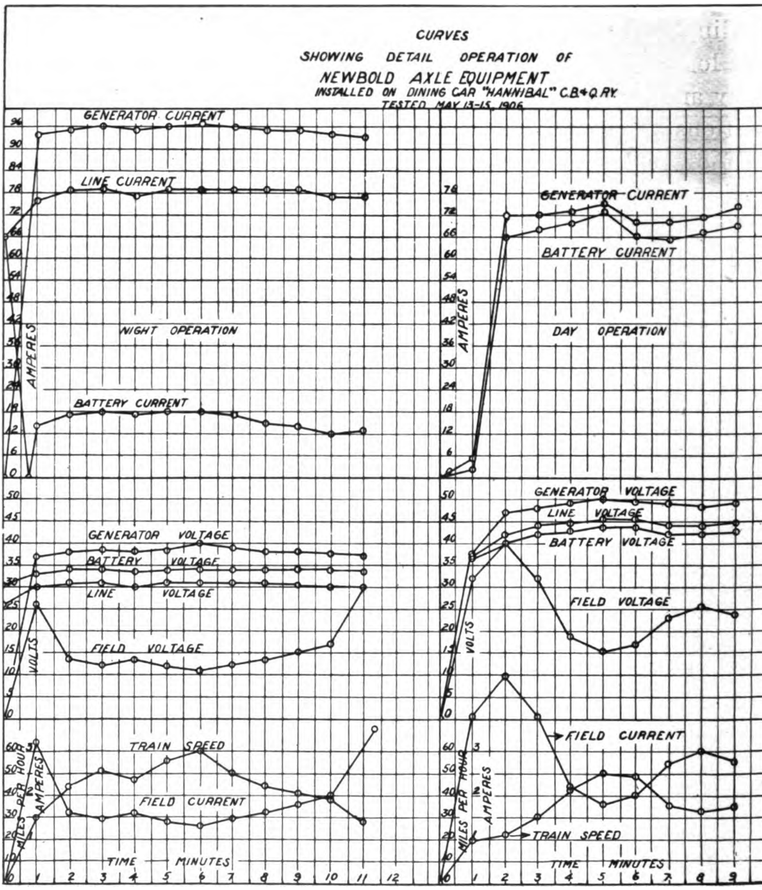

PLATE XXXIV.—CURVES SHOWING DETAIL OPERATION OF NEWBOLD AXLE EQUIPMENT, C. B. & Q. RY.

Trip 3.—Winter Conditions.

Duration of test .... 5 hr. 35 min.
Generator operating .... 3 hr. 10 min.
Total generator output .... 9.62 K. W. Hr.
Total lamp consumption .... 12.42 K. W. Hr.
Total battery charge .... 1.04 K. W. Hr.
Total battery discharge .... 4.66 K. W. Hr.

General.

Generator efficiency—Night operation = 70%
Day operation = 74%

$$\text{Total efficiency, trip 1} = \frac{5.24 \times 72\% \times 97\%}{8.64} = 42.5\%.$$

DISCUSSION OF RESULTS

The results of this test as shown by tables above, and by Plates XXXIV and XXXV, show many interesting features.

In the first place the tables of trips 1 and 2 indicate a pretty fair relation between battery charge and discharge, possibly slightly too great an overcharge but not so destructive as was found in some other tests.

Trip 3 shows an entirely different relation, however, in that the batteries will not receive the proper charge during the winter, unless the regulator is readjusted. To correct for this during the winter months, so that the auxiliary gas light will not have to be used, the regulator setting should be advanced to a value of 160 amperes instead of 95 amperes at which the generator now operates. This would be far beyond the limits of capacity of the equipment as installed on this car, so that the auxiliary gas light would very likely have to be used for part of the time at least.

In the wattmeter readings, correction has been carefully made to eliminate losses due to test connections, which were accurately measured by the voltage drop method with a 0–5 scale voltmeter.

In regard to the curves on Plate XXXIV, attention should be called to the fact that the generator current is practically constant at 95 amperes for night operation but for day operation it drops to about 72 amperes.

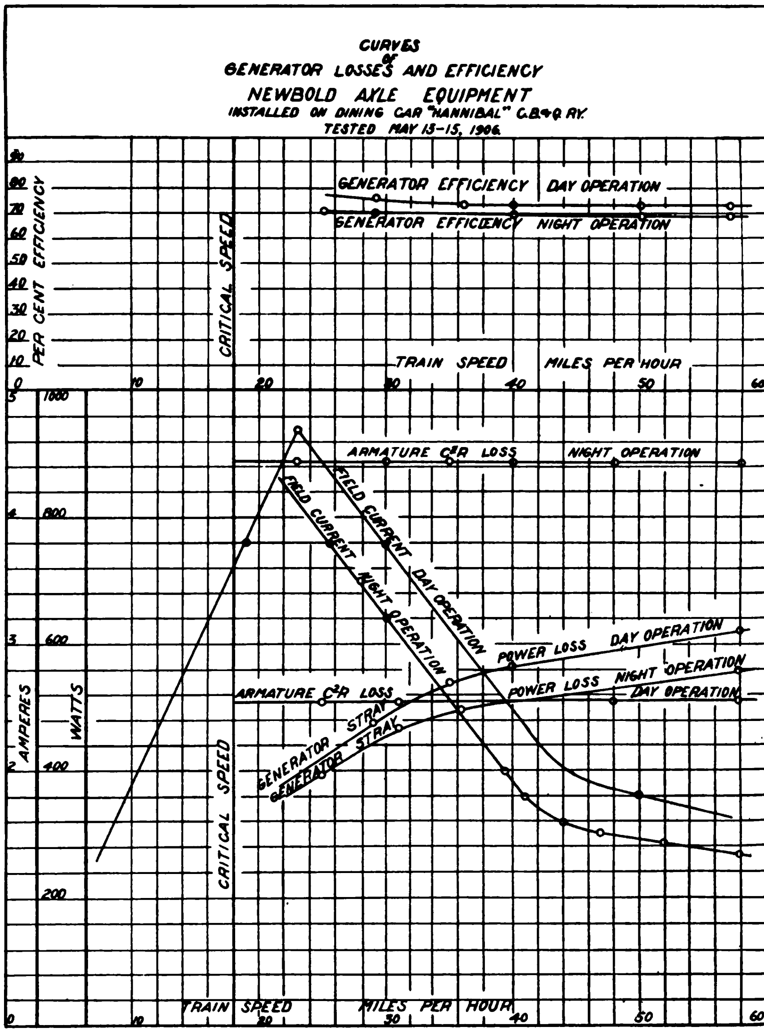

PLATE XXXV.—CURVES SHOWING THE RELATION OF THE VARIOUS LOSSES IN GENERATOR OPERATION.

This illustrates the function of the differential winding on the controlling solenoid of the regulator, which permits the generator current for night operation to be set high enough so that it will charge the batteries somewhat as well as supply the lamps, without causing excessive charging in the day time when the lamps are turned off and all the generator current is absorbed in the battery.

This is the only real value of the differential winding, but it may be said that this is sufficient to warrant its use.

The lamp voltage varied from 25 volts with the generator out of action to 32 volts with the generator in action. It should be noted that in the second column of curves the battery voltage has risen to about 43 volts, which is about 2.7 volts per cell, indicating not only a charged condition of the battery but that of overcharge at a high rate of current flow. In this connection, also, attention must be called to the fact that the battery is not of sufficient capacity for the heavy duty to which it is put.

To illustrate this point: the battery is composed of 16 "National" cells each of 336 ampere hours capacity, supposed to operate at a normal rate of 42 amperes, but it is used on a 75 ampere lamp circuit and is charged at a 72 ampere rate. While this rate would not be considered excessive for short periods of time, it cannot be considered good practice in this instance, as such a high rate causes abnormally high depreciation of the cells.

Test of Bliss Axle Equipment on the Northern Pacific Railway

The equipment manufactured by the Bliss Company is on radically different principles of control from any of the other axle devices and a consideration of the equipment is intensely interesting and instructive.

It consists essentially of a generator located on the truck and driven from a car axle, a storage battery auxiliary such as is common in the other equipments, an automatic switch to close the generator circuit when the critical speed is attained, a regulator to compensate for variable train speeds, and the lighting circuits and fixtures within the car. Within the last year or

two the Bliss Company have adopted the belt drive for their generator but the equipment tested was arranged with a gear drive, accordingly the equipment as tested will be first described.

The generator is of the four pole, iron clad type, suspended inside the truck and geared to the axle by means of a driving gear mounted on one end of a split sleeve or quill surrounding the axle as illustrated in Plate XXXVII. This split sleeve is driven from the axle by means of four driving springs connected to a two armed dog, as illustrated in Plate XXXVI.

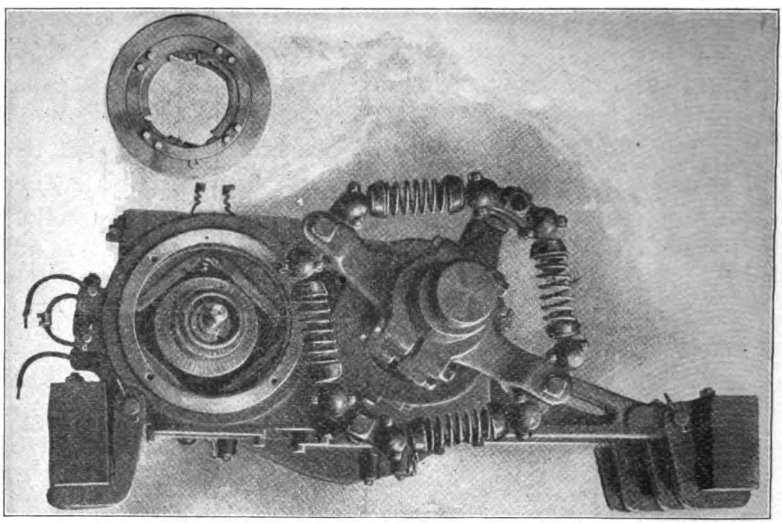

PLATE XXXVI.—SHOWING DRIVING SPRING AND GENERATOR SUSPENSION OF BLISS EQUIPMENT.

The details of the split sleeve are best seen in Plate XXXVII. It runs in and is supported by two sets of roller bearings which are in turn supported by the generator frame so that none of the weight comes upon the car axle, but is all supported by the truck frame. A large clearance is provided between this sleeve and the car axle to allow the axle to take various positions, which it does at high speed, without affecting the generator motion. Since the only connection between the generator and axle is by means of the driving springs, the generator is relieved of all the jarring and blows it would otherwise receive.

It is obvious that with so flexible a connection no careful alignment of the generator and axle is necessary. All the trueing up and lining up are done in the manufacture of the equipment, and its installation is a simple matter.

The generator and driving mechanism are encased in dust-proof cases and are supplied with self-oiling bearings.

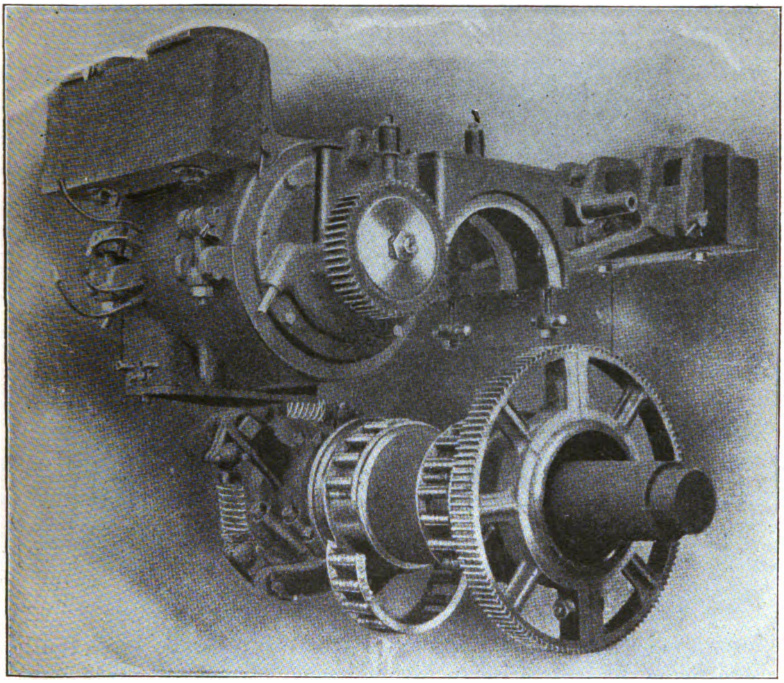

PLATE XXXVII.—SHOWING SPLIT SLEEVE AND DRIVING GEAR OF BLISS AXLE EQUIPMENT.

The *regulator* is the characteristic part of this equipment. Instead of regulating the generator voltage by means of a variable field rheostat, as is done in nearly every other type, a variable electro-motive force is inserted in the generator field circuit in opposition to that impressed by the generator.

This is accomplished by means of a small auxiliary "bucker" armature driven at practically constant speed by a small shunt

motor. The excitation for this auxiliary armature is furnished by the battery charging current, so that the electro-motive force developed in the auxiliary armature is proportional to the battery charging current flowing.

The principle underlying the operation of this regulation is that the charging current flowing into a battery is directly proportional to the rise in impressed voltage above the normal battery voltage; that is, assuming a normal voltage of 64 volts,

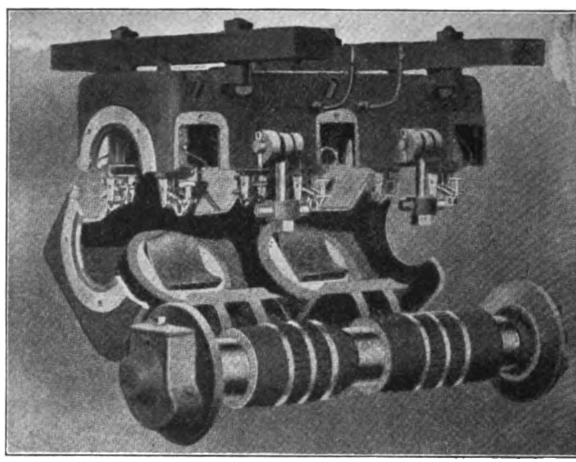

PLATE XXXVIII.—SHOWING "BUCKER" WITH ARMATURE REMOVED.

there will be twice the charging current flowing if 68 volts be impressed than if 66 volts only were impressed, and further there will be three times the current flowing if 70 volts be impressed, etc.

The application of this principle to regulation of generator voltage in this equipment is that a rise in train speed causes a proportionate rise in generator voltage, this in turn causing a proportionate rise in charging current, and this as above mentioned, causes an increase in the bucking electro-motive force in the generator field circuit, resulting in a decrease in field voltage and consequent decrease in field current, and this finally compensates for the rise in train speed. The regulator which effects

this generator control is called the field bucker as it operates in the field circuit of the generator.

The lamp bucker is an additional bucker armature which is very similar in operation to the field bucker, but is used for the purpose of maintaining practically constant voltage on the lamps. It is wound on the same armature as the field bucker and so receives the same excitation, as described above, and generates a counter E. M. F. in the lamp circuit which is at all times proportional to that excitation. This counter E. M. F. compensates for the slight variation in generator voltage caused by varying train speeds, for obviously, as the train speed rises, the generator voltage and battery charging current will rise proportionately, this being necessary to produce regulation. The counter E. M. F. developed in the lamp bucker armature, however, is at all times proportional to the rise in generator voltage above normal battery voltage, and in proper design is made equal to it, so that this lamp bucker voltage at all times compensates for the variation in generator voltage which is inherent in the operation of this equipment. The lamp voltage is thus entirely independent of the speed of the train.

This lamp bucker armature is automatically short-circuited when the lights are being supplied with current from the battery and no regulation is necessary; this is accomplished by the triple contact shown in Plate XXXIX directly over the automatic switch. There are two triple contacts shown in the plate but they represent the same thing, being shown in duplicate only to avoid confusion of lines.

The *automatic switch* is that part of the equipment which causes the generator to be cut into the circuit at the proper speed. Its construction is plainly shown by the wiring diagram in Plate XXXIX and consists essentially of a large coil of fine wire placed across the terminals of the generator, so that when the generator voltage rises to a value equal to that of the battery, the magnetism developed in this coil will be sufficient to draw up the plunger and close the generator switch. There is an additional winding of coarse wire through which all the generator current passes, which intensifies the magnetic pull on the plunger and insures good contact at the switch. This has also

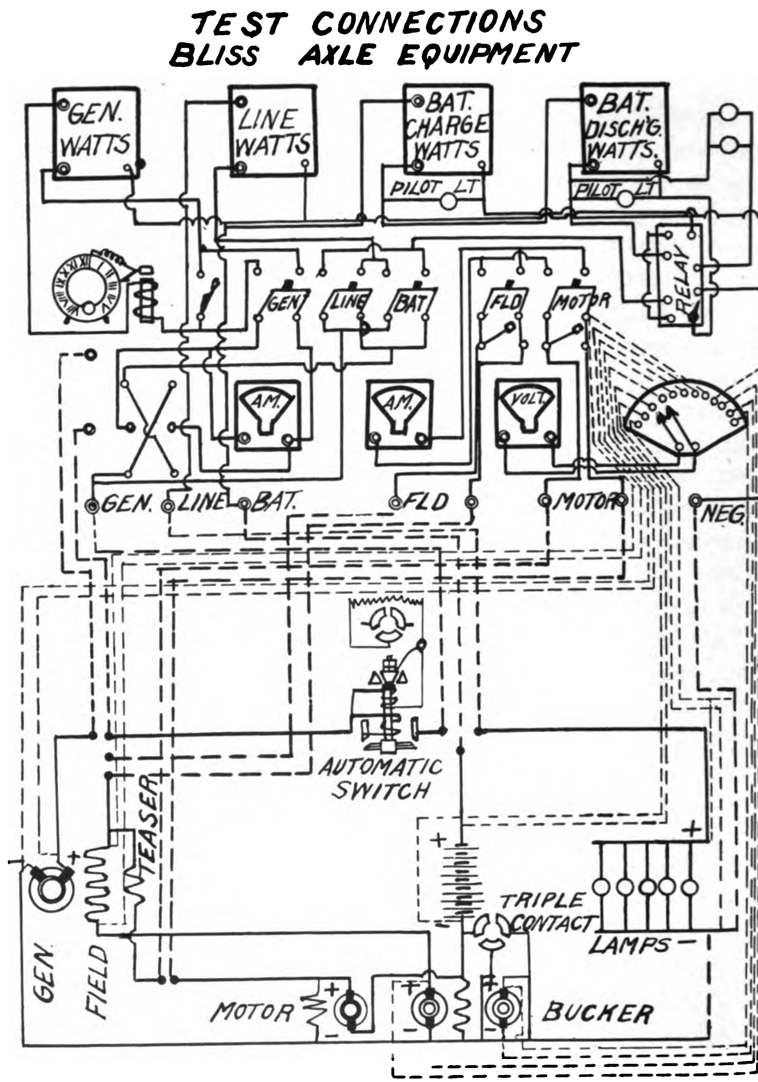

PLATE XXXIX.—TEST CONNECTIONS, BLISS AXLE EQUIPMENT.

an important function in opening the switch on decreased speed, in that the reverse current from the battery will partially neutralize the shunt coil magnetism and cause the switch to open readily at the proper time.

The *battery* is a set of 32 cells of the National type and is of 180 ampere hour capacity. The plates are set in hard rubber jars which are placed in wooden trays in pairs and the whole battery located in two boxes beneath the car as illustrated in Plate XXV on page 70.

POLE CHANGING DEVICE

In this equipment a novel device is employed in obtaining proper polarity in the generator circuit independent of the direction of motion of the car. In that the generator is a four pole one, four brushes are employed, being set 90 degrees apart. These are placed on a movable brush holder which is mounted on a support which permits the holder to rotate 90 degrees, but this support is attached to the frame of the machine.

This angular displacement is limited by a stop. When the direction of motion of the car is reversed it is obvious that the generator will develop reverse polarity, but due to this friction displacement of the commutator brushes the polarity of the circuit would also tend to be reversed, so by this double reversal, constant polarity in the external circuit is obtained.

METHOD OF TEST

In making the test of this equipment it was decided to take the data, as was done in the other tests of axle equipment, in two sets; one set covering the whole performance of the equipment and consisting of wattmeter readings of total watts generated, total line consumption, total battery charge and total battery discharge over the entire trip; the other set being concerned only with the details of operation of the equipment, consisting in taking simultaneous readings of all the various currents and pressures throughout the system as they vary with train speed.

Accordingly a test board was constructed as is shown by the upper half of Plate XXXIX, the lower half of the plate being a diagram of connections of the equipment as in normal operation, the dotted lines showing the temporary wiring to the test board.

Four wattmeters of the ordinary recording type were employed, two Thomson meters and two Duncan meters. The two Thomson instruments were placed in the generator and line circuits, while the two Duncan meters were both placed in the battery circuit, one for battery charge and the other for battery discharge.

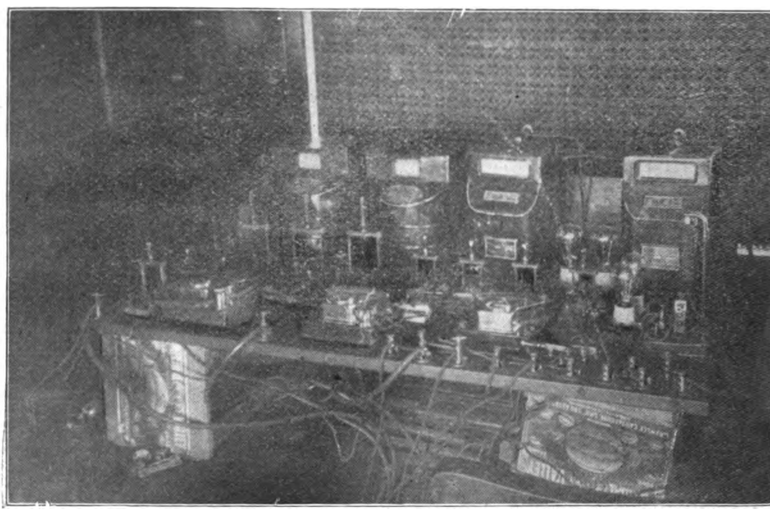

PLATE XL.—TEST BOARD AS INSTALLED IN COACH 963, NOR. PAC. RY.

The separation of battery charge and discharge by means of a polarized relay has been explained on page 62 so will not be considered here further.

A recording clock magnetically controlled was constructed to indicate the total time of generator operation, or more correctly, the total time the generator was not operating, from which the former could easily be deducted. The solenoid of this clock was placed in the generator circuit so that with normal generator current flowing the solenoid would be sufficiently magnetized to draw down the keeper which was in connection with

the balance wheel of the clock, similar to an ordinary stop watch. The adjustment was such that when the keeper was drawn down it would stop the clock, and when the generator current became sufficiently weak the keeper would be drawn up by a spring and the clock would start running, thus recording the time that the generator was inoperative.

A voltage board was constructed as illustrated in Plate XXXIX in order to make all the various voltages readily accessible for reading on one voltmeter.

The method of connection between the test board and equipment is self-evident from Plate XXXIX. The heavy dotted lines indicate where No. 3 wire was used and the fine dotted lines indicate voltage leads. No. 3 wire was used for all main circuit connections so that the error due to test connections might be negligible. Where a circuit was broken in order to insert test instruments into the circuits of the equipment it is indicated by two, and in one case three, solid black dots, which it must be understood, are connected together in normal operation of the equipment.

DATA

Wattmeter and clock readings were taken each morning when the lights were turned off and each night when they were turned on again.

The *detail data* were obtained by taking simultaneous readings of train speed, generator current, line current, battery current, field current, motor current, and generator voltage, line voltage, battery voltage, field voltage, lamp bucker voltage, and field bucker voltage. While it was impossible to make these readings exactly simultaneously they were very nearly so, in that all the readings of each set were taken within a period of ten seconds.

Train speed was determined by counting the rail clicks. In case of a 30 foot rail the number of clicks in approximately 20½ seconds is directly the speed in miles per hour. This was a very convenient and sufficiently accurate method. In taking the speed readings during test, rails were counted for 10.2 seconds only in order to facilitate the taking of these data.

RESULT OF TEST

(See also Plates XLI and XLII.)

Total time of test	74 Hrs.
Generator Operating	49½ Hrs.
Generator Not Operating	24½ Hrs.
Total Generator Output	57.9 K. W. Hrs.
Total Lamp Consumption	28.4 K. W. Hrs.
Battery Charge	8.5 K. W. Hrs.
Battery Discharge	7.3 K. W. Hrs.
Generator and drive efficiency, night operation, computed on basis of belt drive with 97% efficiency	68%
Generator efficiency, day operation, computed on basis of belt drive with 97% efficiency	50%

Average losses of gear drive = 900 watts — 1.2 H. P.

Shortly after starting upon the return trip one of the main driving springs broke and in flying around tore loose one of the generator terminals, and the test was therefore discontinued before the end of the complete round trip.

DISCUSSION OF RESULTS

Referring to Plate XLI which is merely a graphical representation of two different sets of data as taken on the road test, the set in the first column being taken in the evening shortly after the lights were turned on, and the set in the second column being taken in the middle of the afternoon while the lights were out.

One of the most important things to be noted in the first column is the curve of lamp voltage regulation, which is seen to vary from 56 to 58.5 volts in going from a stop to a speed of 50 miles an hour. This compares very advantageously with similar curves of tests of other equipments.

It should be noted also, that the battery charging current is entirely independent of the number of lamps burning, and accordingly continues throughout both day and night. This

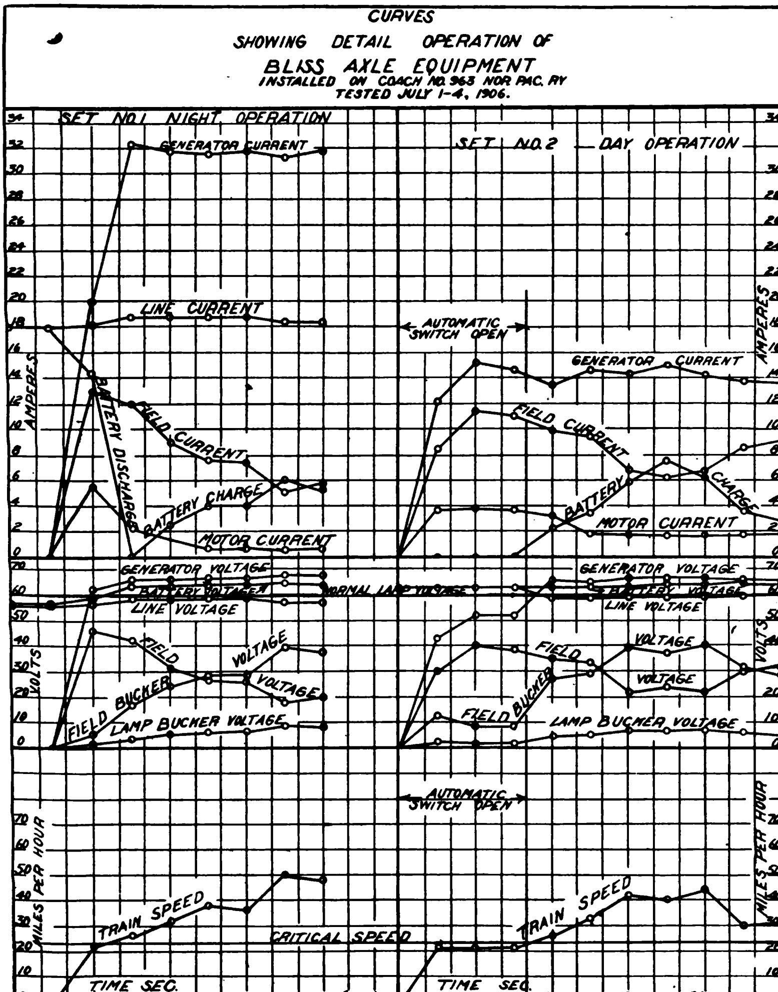

PLATE XLI.—CURVES SHOWING DETAIL OPERATION OF BLISS AXLE EQUIPMENT, NOR. PAC. RY.

charge is, however, dependent upon the train speed, being zero at 25 miles per hour, and gradually rising with the train speed to a value of 8 amperes at 50 miles per hour. This point is more clearly shown in the corresponding curve on Plate XLII in which train speed is plotted horizontally and charging watts plotted vertically. This shows the absolute relation between train speed and battery charge. Here it is plotted as battery watts simply for convenience in comparison, but the approximate charging current is easily obtained by dividing by the normal battery voltage of 60.

This curve is the key to the regulation of the equipment, in that the equipment is operated on principles of battery current regulation, and accordingly the greater the speed the greater the battery current necessary to compensate for that rise in speed. Referring again to Plate XLI it should be noted that the battery charge, field bucker voltage and lamp bucker voltage, increase directly with the train speed, while the field current and field voltage, and motor current vary inversely with the speed. All these relations are shown more plainly by curves on Plate XLII and will be reverted to later.

Comparing the two columns on Plate XLI it may be seen that the operation in the two conditions illustrated is essentially the same except for the change in lamp current, this causing merely a corresponding decrease in the generator current. It should also be noted, before leaving this plate, that the generator current is practically constant at all speeds when the number of lights remains constant. This is due to the fact that for rise in speed the battery current increases while the field current decreases by an approximately equal amount, so that they compensate for each other.

The character of the operation of the equipment may be summarized as follows:

1. The equipment regulates lamp voltage admirably, irrespective of train speed or number of lamps in use, but does not fully regulate in respect to variation in the condition of the battery.

2. The batteries are charged both day and night entirely independently of the lamps in use. This is a point of advantage in

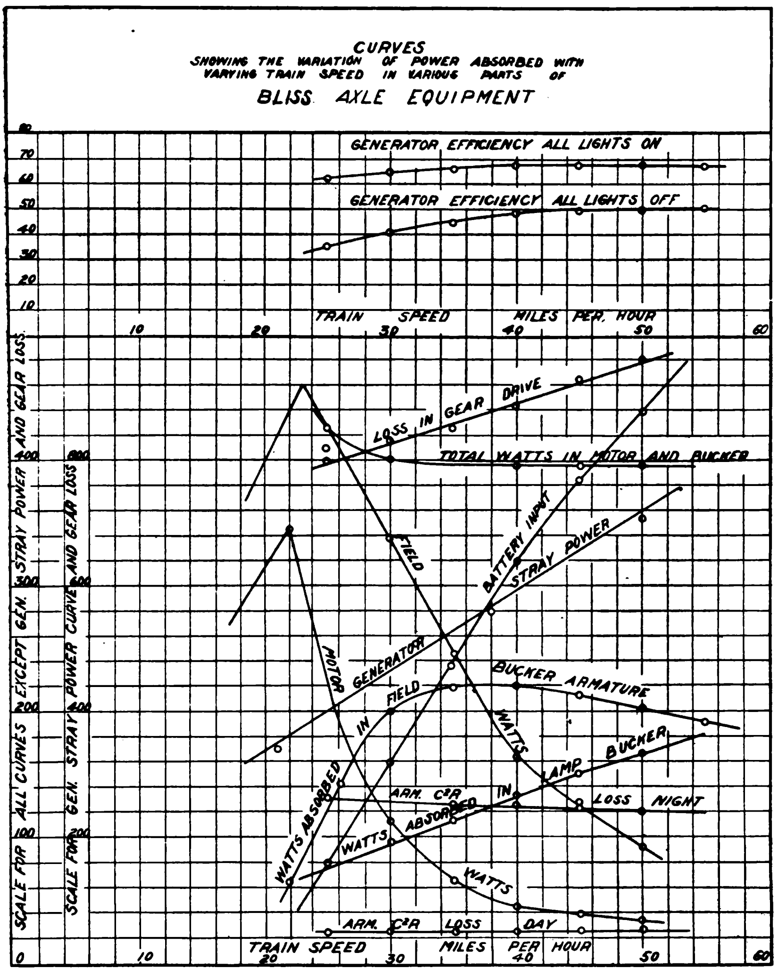

PLATE XLII.—CURVES SHOWING THE VARIATION OF POWER ABSORBED WITH VARYING TRAIN SPEED IN VARIOUS PARTS OF BLISS AXLE EQUIPMENT.

that it allows the equipment to recover at night from a severe discharge. This is not generally the case with the constant current regulation of most other equipments. It also provides that the battery be charged at a low rate over long periods, which is a desirable feature.

3. Battery charging current maintains a fixed relation to train speed independent of the condition of the battery. This has certain advantages and other disadvantages.

Test of Straight Storage Equipment

C. B. & Q. Railway

The test of this equipment was made on a train running between Chicago and Minneapolis, Minn., on the Chicago, Burlington & Quincy Railway. Each car of the train was equipped with a battery of 48 cells of 160 ampere hour capacity made by the American Battery Company. These batteries are all charged and discharged together, as train line connections are made between cars. Suitable switches are supplied in a locker in each car for operating the lamp circuits. The equipment is extremely simple, as no regulating device or complicated mechanism is in the circuit.

The operation of the batteries is as follows:

A charge is given the batteries during the day at Minneapolis, which is followed by the discharge during that night on the run to Chicago. At Chicago the batteries are again charged all day and the night following are discharged in lighting the train on its return to Minneapolis. The charging at Minneapolis is accomplished by means of a Westinghouse gasoline engine-generator set. As soon as the train is backed into the yards, the connections are made to the train line and the charging begins without removing the batteries. Except for a shutdown from 12 to 1 at noon, the batteries are charged continnously from 8:30 A. M. to 5:30 P. M., using a current of about 40 amperes to the train of four cars.

At Chicago the batteries are again charged for about the same period from a charging station at the 12th Street Round House,

which is provided with a 90 Horse-power Westinghouse Engine belted to two dynamos, one of 15 K. W. capacity and the other of 25 K. W. capacity.

METHOD OF TEST

In making the test of this equipment, switches were placed in the battery circuits of each car by means of which an ammeter could be inserted to measure the current flowing. Readings of current and voltage were taken from each car at fifteen minute intervals. The results given in the following table are the averages of three separate charges and three separate discharges which were made in the test.

RESULT OF TEST

Chair Car No. 501.

total lamp consumption (3 trips)	17.94 K. W. Hr.
Total battery charge (3 days)	38.6 K. W. Hr.
Watt efficiency	46.5%
Total lamp consumption (3 trips)	20.9 K. W. Hr.
Total battery charge (3 days)	45.7 K. W. Hr.
Watt efficiency	45.7%

Pullman Sleeper "Apollo".

Total lamp consumption (3 trips)	26.1 K. W. Hr.
Total battery charge (3 days)	51.9 K. W. Hr.
Watt efficiency	50.3%

Chair Car No. 4151.

Total lamp consumption (3 trips)	17.4 K. W. Hr.
Total battery charge (3 days)	31.5 K. W. Hr.
Watt efficiency	55.2%

DISCUSSION OF RESULTS

In discussion of the results of this test, attention should be called to the low efficiency of the batteries as given on the preceding page. This is largely due to the fact that the batteries were old ones and had been operated in this service for several

years. It is also somewhat due to the fact that the batteries were slightly overcharged each day, this, however, not being much more than should be given to keep the plates from sulphating.

In regard to the general operation of the equipment it may be said to be satisfactory. The lights at the beginning of the trip are connected to a freshly charged battery and make a very good showing in lamp brilliancy. Later in the night the voltage falls somewhat, but the lights are not needed so much at that time, so that it is not objectionable.

CHAPTER IV

THE AXLE LIGHTING PROPOSITION

In presenting this chapter it will be assumed that the reader has a practical understanding of the ordinary apparatus in connection with an axle equipment, such as the generator, battery, lamps, pole changer, automatic switch, regulator, etc., and in this chapter will be considered only the principles underlying the operation of that equipment.

The fundamental principles will be treated in the order of their importance and may be outlined as follows:

a. Generator control.
b. Lamp voltage regulation.
c. Generator drive.
d. Protection of storage battery from excessive overcharge.

(a) *Generator Control.*—There are several principles upon which such a control might operate, and there are as many such regulators in actual operation.

1. Probably the simplest one is that which depends upon the belt slipping at the high speeds so that the generator runs at a constant speed irrespective of variable train speed above a certain predetermined limit. Such an equipment is described on page 11.

2. Then another might be dependent upon armature reactions at the high speeds controlling the generator voltage. Such an equipment is described on page 16.

3. Regulation could also be effected by means of a differential winding on the generator fields to decrease the excitation as the generator voltage, and hence battery current, increased. Such an arrangement is sometimes employed, where desirable,

as a modification of the Bliss Axle equipment, replacing the bucker scheme.

4. The last and most used in this country is that type of regulation which controls the generator current by varying the generator field current to compensate for rise in speed. Upon this last principle are based all the successful regulators in the American market today.

In the manner in which this variation in field current is obtained proportionate to rise in train speed, there is a wide diversity of methods and mechanisms. They may, however, be divided into three classes; those of Constant Current Control, Battery Current Control and Voltage Control.

Further, it is interesting to note in a comparative way the various means by which the regulation is effected.

1. In the Consolidated Axle Equipment a field rheostat is operated by means of an auxiliary motor. See page 56.

2. In the Newbold System the floating plunger of the solenoid is attached to a balanced rheostat arm. See page 77.

3. In the United States Equipment the floating plunger of the solenoid presses directly upon a pile of carbon blocks which forms a variable resistance in multiple with the generator fields. See page 21.

4. In the Deutsch System a field rheostat is operated by compressed air, the supply of which is affected by the controlling solenoid. See page 25.

5. In the Everett Regulator a variable resistance in the form of carbon contacts is inserted in multiple with a permanent field resistance, these carbon contacts being fastened directly upon the floating plunger itself. See page 24.

6. In the McElroy Axle Equipment a small auxiliary motor operates the field rheostat, the motor running only when regulation is necessary. This motor is controlled by the regulating solenoid. See page 18.

7. In the Bliss Axle Equipment a small motor drives an auxiliary armature which generates a variable counter-electromotive force in the generator field circuit. This is better known as the "bucker," and is described on page 98.

The first class of regulators, those of constant current con-

trol, comprise all those regulators which depend upon the magnetic pull of a solenoid energized by the generator current. Of the modern American equipments on the market, those having this type of regulation are:

The Consolidated Axle Equipment .... p. 56.
The Newbold Axle Equipment .... p. 77.
The United States Axle Equipment .... p. 21.
The Deutsch Axle Equipment .... p. 25.
The Everett Aegulator .... p. 24.

In the second class, that of battery current regulation, there is only one equipment manufactured, the Bliss Axle Equipment, page 95.

Likewise in the third class, that of voltage control, there is only one equipment in the American market, the McElroy Axle equipment, page 18.

In a consideration of the relative merits of these three classes of regulators, it should be remembered that none of them regulates for constant generator voltage, in fact, such a regulator would be impracticable on this kind of service, inasmuch as it is necessary to raise the impressed voltage in order to charge the battery; but the writer does, in this connection, wish to emphasize the fact that the regulators for constant generator current, as well as those of battery current control, will cause the same charging current to flow whether the batteries are in an exhausted state and need the charge, or whether they are, at the time, fully charged and are being destructively overcharged; that is, the regulation is not dependent upon the voltage at which it operates. This point is easily proved, inasmuch as the regulation itself depends upon this very current flow.

This should indicate the extreme importance of proper setting of the regulator for the conditions of each particular run on which cars are engaged, in order that the time of destructive overcharge may be a minimum. On many runs, however, this is impossible due to the uncertain and unknown conditions, and in such cases in order to obtain satisfactory and economical operation a protective device to prevent excessive charging such as described on pages 126 to 132 is desirable.

The equipment in the class operative by voltage control is

that described on page 18. The principle underlying the operation of this regulator is one which should, if properly carried out, largely eliminate the objection in regard to overcharge of the battery, which is often found with the other types, for in this type of regulator the charging current decreases by any predetermined ratio as the battery becomes fully charged, as explained on page 19.

It should be noted that in the constant generator current regulation, the battery charging current when the lamps are turned on is very low or nothing at all (see Plate XXXI), but that when the lights are turned off it rises to a value equal to the normal generator output, so that the charging is practically all done in the day time; while on the other hand with battery current regulation, such as the Bliss type, the battery charge is irrespective of the lamps in use, that is, the batteries are charged practically all the time the train is running. The amount of charging current flowing varies with the train speed as shown on Plate XLI in the test of that equipment, but the average value of charging current is proportional to the average train speed above the critical speed.

A differential winding is provided on many so-called constant current regulators, which causes the generator to supply a considerably larger current when all the lamps are turned on than when they are all turned off. This permits the battery to be charged considerably during night operation (see Plates XXIII and XXXIV) as is the case also with the battery current regulation of the Bliss equipment (see Plate XLI).

This may be said to be a good point in the operation of these equipments, as it provides that the battery may recover quickly from a serious discharge even while the lamps are all turned on.

In fact in this connection it is the firm belief of the writer that, where the generator is of sufficient capacity, this differential winding on the constant current regulators should be increased to such a value that it will maintain the battery charging current practically constant throughout both day and night operation. This, as mentioned above, would provide speedy recovery of the battery from any heavy discharge and would also

render equipment more independent of the variation between winter and summer operation as discussed on page 117.

CALCULATION OF REGULATOR ADJUSTMENT.

In regard to the calculation of the proper adjustment of the regulator, it may be said that no definite methods of procedure can be laid down, as it varies with each type of regulation and is at best only an approximation, but in general for those regulators which maintain constant generator current and have no differential winding, the regulator should be set so that the aggregate ampere hours charge of the battery during the day time should be about twice as great as the aggregate battery ampere hours discharge at the slows and stops during the night. This should be sufficient to care for low battery efficiency and for recovery from emergency discharges. Attention, however, should be called to the fact that the batteries are discharged at night not only while the train is stopped but all the time it is below the critical speed of about 20 miles per hour, and the estimation of the ampere hours discharge must be based on this time. This must be given special attention when running slow on mountain travel or running through the yards near a large city where slow speed is necessary.

In making the calculation above, it must be considered whether or not the generator current at the setting calculated is larger than the normal lamp current added to the average field current, and proper correction be made for this all-night charge or discharge as the case may be.

In making calculation of the proper setting when a differential winding is added to the regulator the problem is more complicated and liable to error, but in general the same method may be followed as is mentioned above in connection with constant generator current regulators, except that the difference between the operation when the lamps are all on and are all off must be kept in mind. In allowing for this difference in operation it must be remembered that the difference is caused by the lamp current flowing through the differential winding, so that the difference between the day operation without the lamps

on and the night operation with all the lamps on is constant whatever be the regulator setting. That is, if the regulator is set at 30 amperes in day operation and 40 amperes with all lights on, and then the regulator be changed so as to deliver 35 amperes in the day operation, the night operation will be correspondingly increased to 45 amperes, etc.

When making calculations for the setting of regulators in connection with Pullman sleepers where about two-thirds of the lights are turned off as the passengers retire, the calculation is still more complex and should be checked by experience and trial on the particular runs, as the effect of the differential winding decreases as the lights are turned off so that if the regulator had operated at 35 amperes during the day and 45 amperes when all lamps were turned on it would be operating at about 38 amperes when only one-third of the lamps were lighted; that is, there is a differential effect of only one-third normal.

The calculation for the proper setting of a battery current regulator of the Bliss type is more simple and of a smaller probable error. Since the charging current is proportional to the average train speed, or more correctly is proportional to the average train speed above the critical speed, (see page 106) all that is required in setting this regulator is to know the average train speed from the time table, the total battery discharge in ampere hours while the generator is not operating, and the total time of generator operation. The regulator is then adjusted, when the average train speed is attained, to such a value that the then obtained current multiplied by the total time that the generator is operating will give an ampere hour charge equal to about twice the total ampere hour discharge. This will ordinarily be sufficient to allow for low battery efficiency and for recovery from emergency discharges. It should be noted that no consideration need be given to the number of lamps used nor the hours of lighting, this battery charge being independent of the lamps.

It is readily apparent that the calculations given above are at best merely approximations, in that they involve many assumptions which cannot be accurately determined except by special tests. It is easy to adjust an equipment so that it gives

sufficient charge to the battery, for if it does not, the fact is immediately indicated by failure of the light, but on the other hand to prevent an excessive overcharge is a more difficult matter as the battery may be practically ruined before the effect will be especially noticeable unless the battery is under careful supervision at the ends of the run.

This excessive overcharge can, however, be easily detected and remedied by placing a testing wattmeter in the battery circuit for at least one round trip of the car. This will run, say forward on charge and backward on discharge, so that the difference in the reading before and after will represent the overcharge. Not exactly so, however, for it must be remembered that the meter will measure watts charge and watts discharge, and that a proper charge must be considerably in excess of the discharge, especially where both are measured in watts. Then for proper operation of the equipment this apparent overcharge, as indicated by the meter, should be about equal to the total amount discharged from the batteries in lighting the lights when the generator is not operating. This can be readily estimated from the discharge at stations. Any railway company operating axle equipments should purchase at least one recording wattmeter of a good standard make which is of sufficiently robust construction to withstand the severe service and should use it for testing in the manner just suggested. This will provide an easy and accurate method of determining the operation of an axle equipment.

In regard to the variation of the regulator adjustment throughout different times of the year, attention should be called to Plate XLIII. The cross lined portion indicates the hours in which the lamps are lighted throughout the year. It is noted that the hours of lighting are assumed as falling within one hour before sunset and one hour after sunrise, this being about the average time as found in the pursuit of these tests.

It is noted that the variation is from 10 hours in June to 17 hours in January. This represents an increase of about 70% in the total hours of lighting in January over those for June.

In regard to the resetting of the regulator to compensate for this variation, it may be said that the necessary variation in

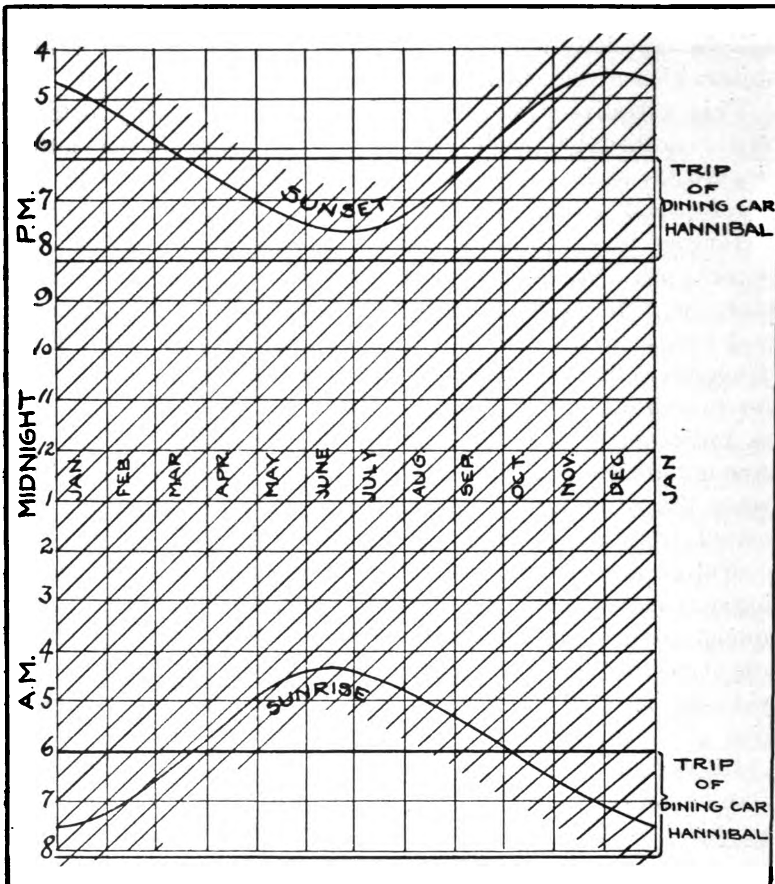

PLATE XLIII.—CURVES SHOWING HOURS OF LIGHTING.

regulator setting is of no such magnitude as 70% except in special cases, but is nevertheless of sufficient value to warrant consideration.

For constant generator current regulators which have no differential winding, it is readily seen that the increased total hours of lighting will affect the operation in two ways; it will increase the probable battery discharge at stops, and will decrease the total hours of charging the battery during the day. The former may be assumed as directly proportional to the 70% increase in hours of lighting, while the latter will be proportional to the decrease in available hours for charging the batteries which is seen to be seven hours or about 50% of the total hours available for charging outside of lighting hours during June. These combined would require an increase to 4½ times the normal rate of charge, or a 350% increase, if all the charge were to be done during the seven hours daylight run in January, but as this increase in setting will be effective throughout twenty-four hours, instead of only seven hours upon which that figure is based, the necessary increase in the average charging current will be only 100%.

It has been found in pursuit of the tests that the battery charge generally comprised about ¼ of the total output of the generator, so that reducing the calculation to a basis of generator current, it is found that: For all constant current regulators operating on trains having a 24 hour run or over, the regulator adjustment should be increased approximately 25% for operation in January over that for operation in June.

For regulators operating on principles of battery current control the situation is somewhat different. As previously indicated, the charging of the storage battery takes place all the time the train is above critical speed and is independent of the lamps. Now again, assuming the car is operated on a 24 hour run, the increase of 70% in the hours of lighting during the winter months will only affect the battery discharge and will not affect the charge, so that the readjustment of the regulator need be only such as will compensate for the increased discharge. However, inasmuch as the battery current comprises the total regulator current, this increase of 70% in the battery

discharge must be compensated for by a direct increase of 70% in the regulator setting. This, however, gives a wrong impression in that apparently the necessary variation of adjustment is much greater than the 25% found in the case of the constant current regulators, but inasmuch as the regulator current comprises the whole generator current in the case of a constant current regulator, the 25% variation will represent a greater ampere variation than the 70% variation of the battery current regulator. The necessary variation in the two different systems expressed as a ratio in amperes would be approximately 9 amperes in the former and 5 in the latter.

The voltage control machine would, of course, require no readjustment other than to provide for the variation in a charging voltage due to the low temperature in the winter months.

In regard to the variation in regulator settings mentioned above, adjustment should be made perhaps four times a year, preferably March 1st, May 1st, Aug. 1st and Nov. 1st. This is allowing a probable error of 2 or 3 amperes in the adjustment, which is possibly too great for good practice, but is, however, unavoidable, due to the uncertainties of operation.

In the foregoing, consideration has been taken only of those equipments operating on a 24 hour run or over. In regard to the equipment on short runs of which the dining car "Hannibal," (page 89 and Plate XLIII) is an example, the variation is much greater and at the same time more uncertain. It has been computed on page 93 that during the summer months this regulator should be set at 86 amperes, while during the winter months this should be increased to 160 amperes, representing an increase during January of 87% over the operation during June.

This should be sufficient to emphasize the necessity of proper attention to these short run equipments. The regulator on the car in question might well be adjusted as often as once in two weeks, and even that would allow a probable error as great as 4 amperes in the adjustment at certain times.

(b) Lamp Voltage Regulation.—Before beginning the discussion of lamp voltage regulation it is important that the un-

derlying principles which make such regulation necessary be well understood.

Plate XLIV, taken from Lyndon's *Storage Battery,* represents the voltage variation of a storage battery while being charged and discharged at the normal rate. It is noted that the charging voltage is considerably in excess of the discharge voltage and that the curves are approximately parallel between (a) and (b). As the charge is continued, however, the charging voltage finally rises rather abruptly to a voltage at which it will remain so long as the act of charging is continued, this point indicating that the battery has been fully charged.

In the operation of axle equipments it may be said that the battery voltage when the lamps are turned on, oscillates back and forth between these two curves, lying on the discharge curve for a few minutes while at stations and on the charging curve while running between stations. Inasmuch as the lamps are to be operated in parallel with the battery, it is evident that the oscillation back and forth between the two curves must be compensated for if constant voltage is maintained at the lamps, so that the lamp voltage will practically follow the lower of the two curves, as is the case in most of the lamp regulators. It is noted, however, that this curve of discharge voltage which may be considered as the point of reference in most equipments, is itself not constant but varies considerably throughout the battery capacity, and it is this feature that is the neglected consideration in most lamp voltage regulators.

It must be made clear, however, that under ordinary circumstances with proper adjustment of the regulator, the battery does not become fully charged during the night, but rather operates over a range well within limits, so that the curve of reference mentioned may vary only slightly. There are, however, many cases, especially on Pullman sleepers, where the battery does become fully charged during the night, at which time the charging voltage is maintained at maximum value. At this time the "night circuit" of lamps is severely strained as indicated on Plate XXVII, page 76. This point is discussed later in the chapter in connection with the proper regulators.

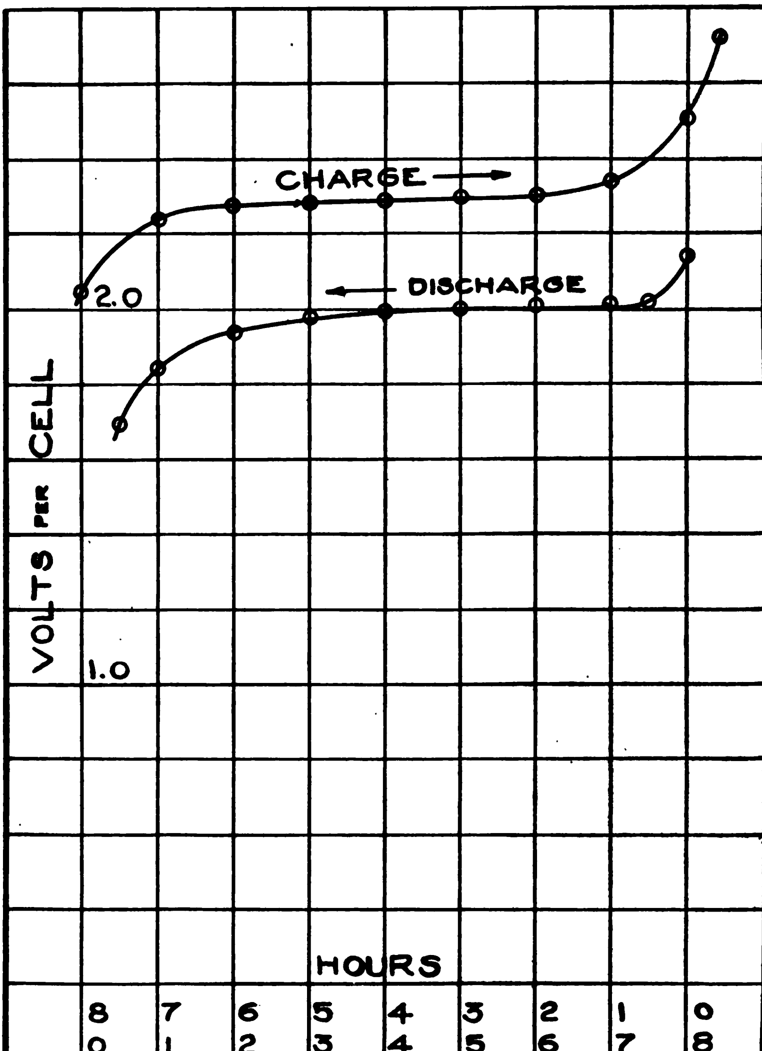

PLATE XLIV.—CHARGE AND DISCHARGE CURVES.

The oscillation of battery voltage as mentioned above makes it necessary to insert some kind of voltage drop in the lamp circuit when charging takes place, in order to compensate for this rise in voltage and to maintain constant lamp voltage. In the modern American equipment this is accomplished in four different ways:

1. By inserting a certain definite resistance in the lamp circuit when the generator first begins to operate.

2. By inserting a resistance in the lamp circuit, the value of which depends upon the number of lamps in use.

3. By automatically inserting a variable counter-electro-motive force in the lamp circuit.

4. By automatically inserting a variable resistance in the lamp circuit controlled by a special regulator.

(a) The first case of inserting a certain definite resistance into the lamp circuit is employed on numerous equipments, among which are the old type Consolidated equipments and the United States equipments. It consists in simply inserting this resistance when the generator begins to operate. This is accomplished in various ways as described in connection with those equipments and will not be considered further. In discussion of the operation of this arrangement it should be noted that this resistance is designed to compensate for the difference between the charge and discharge curves as shown on Plate XLIV, but it should be also noted that there must be normal full load lamp current flowing to produce the desired drop.

It may be said that under the conditions for which this is designed it may be made to give satisfactory regulation, but for the variable conditions as commonly met with in actual service it is not entirely satisfactory. For instance, as part of the lamps are turned off, the IR drop in the resistance will decrease proportionally, so that the lamp voltage will more nearly follow the battery voltage. At this time, with constant current regulators, the battery charging current will increase and accordingly the battery charging voltage will be increased so that the increase in lamp voltage will multiply as the lights are turned off. This type of lamp regulation will not, of course, compensate for the rise in voltage due to increased battery charge mentioned above,

and the lamp voltage may be said to depend upon the number of lamps in use and the condition of battery charge.

(b) The second class, a modification of the above, is that used on the Newbold equipment and consists in connecting separate portions of the lamp circuit rheostat to the switches of the various lamp circuits, so that as each lamp circuit is turned on, a portion of the total lamp resistance will be short circuited, and, as the lamps are turned off, the total lamp resistance will be increased so that with a proper proportioning of parts the IR drop of the lamp rheostat may be said to be independent of the number of lamps in use. The Newbold regulator does not, however, compensate for the rise in battery voltage due to the battery becoming more fully charged. In fact, when part of the lamps are turned off, the battery will charge more rapidly, and though the IR drop in the lamp rheostat is independent of the number of lamps in use, the total regulation cannot be said to be independent of the number of lamps in use. In fact, this rise in battery voltage as represented by the upper part of the curves of Plate XLIV, may be such as in some cases to obliterate entirely the good offices of the variable rheostat.

This principle of making the lamp circuit rheostat vary with the lamps in use does not add any serious complication to the operation of the equipment, and the advantages gained undoubtedly warrant its use.

(c) Another type of lamp regulator is that described on page 98, as used on the Bliss equipment. It consists essentially in placing a counter-electro-motive force in the lamp circuit to compensate for the rise in battery voltage. The value of this counter-electro-motive force, as previously described in connection with the Bliss equipment, is directly proportional to the rise of battery voltage and it therefore regulates accurately in this respect.

Inasmuch as a variable counter-electro-motive force developed in a low resistance armature is employed instead of a rheostat, the lamp regulation will be independent of the number of lamps in use. The regulator does not, however, compensate for the rise in battery voltage due to a more fully charged

condition of the battery, but as above mentioned, under ordinary conditions the battery is operated well within limits, so that the excess voltage of overcharge is not often attained.

The point, however, is maintained in regard to all three types of regulators thus far mentioned, that, in case *the battery does become fully charged while the lamps are burning, the lamp voltage will rise directly with the battery voltage* represented by the upper curve on Plate XLIV. This is sufficient to indicate the necessity of caution in setting the generator control so that the battery will not become fully charged at night.

(d) The last of the four types of lamp regulators mentioned above is the one manufactured by the Consolidated Axle Equipment Co., described on page 58.

It consists essentially of inserting a variable rheostat in the lamp circuit which is controlled by a special solenoid regulator and is operated by an auxiliary motor as described in the above reference. It is readily seen that, inasmuch as this regulator is controlled by an independent solenoid, it will, if properly adjusted, be entirely independent of the number of lamps in use or condition of the battery charge, and will be limited in its accuracy of regulation only by the probable error in the controlling solenoid.

(c) *Generator Drive.*—All the methods used in driving the generator from the car axle may be divided into three classes:

1. Belt Drive.
2. Gear Drive.
3. Friction Drive.

The first mentioned type, that of the *belt drive,* is the most commonly used and apparently the most successful. It has the advantage of simplicity, and is readily accessible in case of repairs. Failure of the drive due to the loss of the belt may be remedied in a few minutes. It forms a flexible connection so that the blows and shocks of the car axle are not transmitted to the generator.

The *gear drive* contains complications which render it more inaccessible and difficult to repair. Such an equipment has been described in connection with the test of the Bliss Axle Equipment, so the details of construction will not be repeated.

It may be said, however, that this kind of a drive has an advantage over belt drives under certain extreme conditions where the under rigging becomes covered with ice, but as this condition is seldom met with on most railways it may be disregarded in most cases, and the mechanical disadvantages seem to outweigh any advantages.

In regard to the power absorbed by the gear drive tested, it was found to be about 25% of the total generator output when all the lamps were turned on. This is considerably higher than that generally experienced under similar conditions of load with a belt drive which has in these tests been assumed as 3%. This assumed belt loss may be somewhat low but was considered as a fair approximation of the real conditions.

The *friction drive* is the least used of any of the drives. At an early date in his development work, Mr. W. L. Bliss devised and patented such system for use in connection with single lighting equipment and the same system with modifications is now under consideration by the Bliss Co.

(*d*) *Protection of the Storage Battery from Excessive Overcharge.*—As pointed out in this discussion, it is inherent in the operation of all current regulators to overcharge the battery to a greater or less degree, depending upon the error in setting the regulator, and as the resultant high battery depreciation is a prominent factor in the cost of "axle lighting," a consideration of methods of reducing this depreciation is at once interesting and instructive.

Prevention of this overcharge of the battery can best be effected by rendering the generator inoperative after the battery has become fully charged and maintained so whether at high or low speeds until the battery requires replenishing. Obviously this point at which the battery does become fully charged is of vital importance in this consideration and because of the peculiarly variable nature of a storage cell, the accurate determination of this point by automatic apparatus presents a problem of considerable difficulty.

Mr. W. L. Bliss has designed such an apparatus which depends for its operation upon the rise in voltage of a battery as it becomes charged. A solenoid of fine wire is placed across the

terminals of the generator and when the automatic switch is closed the solenoid is also across the battery terminals. As the battery becomes fully charged its voltage will rise to such a value as will trip the solenoid plunger which opens the field circuit of the generator. This would of course reduce the generator voltage to zero and open the automatic switch, but such result would release the solenoid plunger which would fall and again re-establish the generator field and repeat the cycle of operations. What is wanted is to kill the generator to a point so low that the automatic switch will open and remain open, but it is not desired to kill the generator completely as some voltage is required to maintain the solenoid plunger in its drawn position. Accordingly, as soon as the shunt field circuit is opened, a stable, though weak field is reestablished from the battery and so a low generator voltage is maintained. This, however, even at the high speeds, is not of a value sufficient to close the automatic switch. When the train stops, the solenoid will be no longer energized and so will allow the plunger to fall, reestablishing the generator shunt field circuit. If no current has been taken from the battery since the time the cut-off operated, the cut-off will operate again very shortly after the generator becomes operative. If, however, current has been taken from the battery in the meantime, the generator will continue to operate until it has replaced this and until the battery again becomes fully charged, when the cut-off will again operate.

One car on the Pennsylvania railroad has been equipped with this controlling device, but as yet no definite information can be obtained in regard to its operation.

A controller, differing radically from that above, has recently been developed by the writer. It consists essentially of a controlling wattmeter which registers charge and discharge of the battery, rotating in one direction on charge and in the reverse direction on discharge.

This wattmeter, through a set of reducing gears, operates the dial pointer E (see Plate XLV), turning it in a clock-wise direction on discharge, and in the reverse direction on charge. The reducing gears are so proportioned that one complete charge or discharge of the battery will turn the dial pointer E through

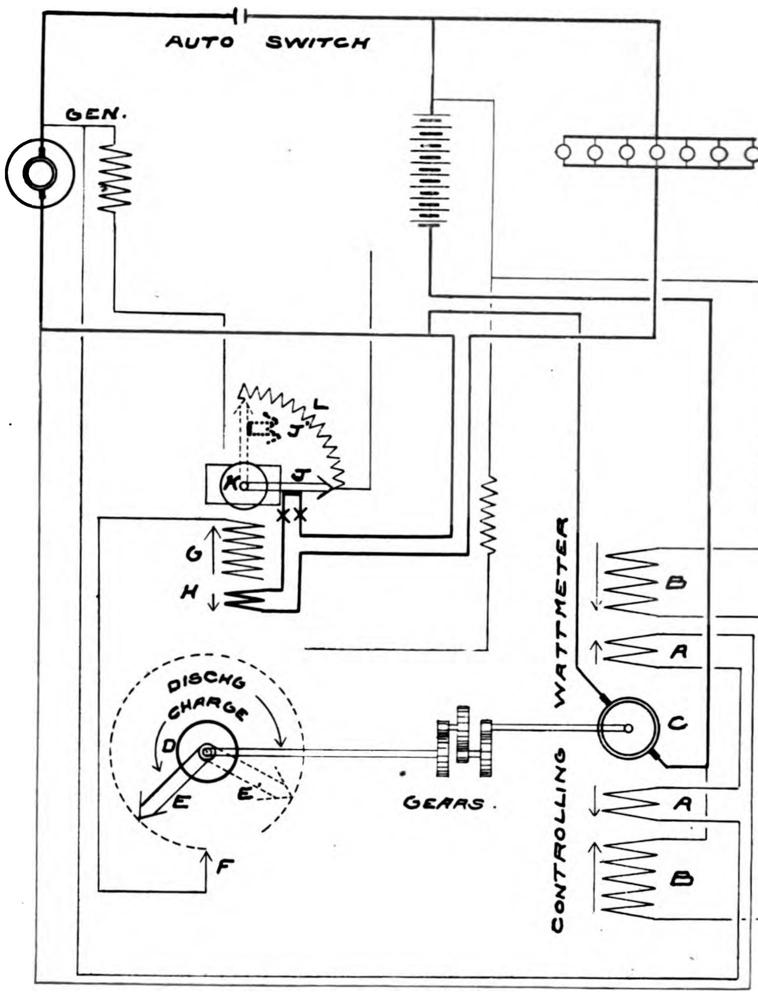

PLATE XLV.—WATTMETER CONTROL OF BATTERY CHARGE.

slightly less than one revolution. The position of the dial also indicates the condition of the battery, it being in a position E^1 when the battery is completely discharged and as the battery becomes nearly charged may take a position at E. As the charge is continued to completion the pointer will be slowly moved toward the point F. Then when the battery is fully charged the pointer E will make contact with the contact point F.

This contact will complete the circuit through the coil G of the circuit breaker and trip the circuit breaker, causing the arm J to assume a position J^1. In doing this it automatically and slowly inserts the resistance L into the generator field circuit. This causes the generator voltage to fall below that of the battery and opens the automatic switch in the ordinary way. A glycerine check K is supplied which causes the arm J to move very slowly, thus insuring against a disadvantageous discharge upon opening or closing the generator field circuit. The whole equipment will now be inoperative all the rest of the day till the lights are turned on at night. In turning on the lights the porter pulls down the arm J, which also serves as a main switch in the lighting circuits, and restores normal operation of the equipment. It is impossible for the porter to obtain any light until he does pull down this arm J, so this part of the operation is entirely reliable.

The lamp current flowing through the differential coil H prevents the circuit breaker from opening when the lamps are turned on even though contact be made at the point EF, so that the night operation of the equipment is in no way interfered with even though a charged condition of the battery maintains.

In providing for low battery efficiency a differential winding A of the wattmeter fields is placed across the generator terminals, so that when the generator is operating and the battery is being charged the magnetic field within the wattmeter is of less intensity than when the generator is not operating and the coils B only are effective. This causes the meter to run slower on charge for an equal power consideration, the increase in speed being easily adjusted to care for any predetermined battery efficiency recommended by the manufacturers.

DISCUSSION

As mentioned above, the problem of automatically controlling the charge of a storage battery is a rather difficult one because of the peculiarly variable nature of the storage cell. There are a number of factors which alter the operation of a battery very materially and in fact it may be said that there is no function in the operation of a battery which is definite or even reliable where any degree of accuracy is desired.

In the first method of control mentioned, it is assumed that when a battery becomes fully charged, its voltage rises to some definite value at which point the controlling solenoid will operate. This, however, is not in accordance with the actual conditions of battery operation, for it cannot be said that a battery rises to any certain voltage when it becomes fully charged; this voltage at overcharge is dependent upon several factors, chief among which is the rate of charge, but even assuming that as normal there are other factors which very materially affect it. Variations in temperature and density of the electrolyte, and age of the elements, are factors which change the voltage at overcharge very considerably, so that instead of considering the voltage at overcharge as 2.6 volts per cell, with normal charging current flowing, we must consider it as varying from 2.5 to 2.65 volts per cell, depending upon the temperature and density of the electrolyte and age of the elements. Accordingly, any device depending upon this voltage for its operation, even though that apparatus itself be very sensitive and reliable, cannot operate with more than temporary success.

The second mentioned controller is based on a watt hour principle and depends, for its accurate operation, upon the assumption of a certain efficiency of operation of the battery.

This efficiency of operation, however, is not a definite value but is dependent upon several variable factors. It depends primarily upon the charge and discharge rates, and upon the charge and discharge intervals; that is, whether the battery is alternately on charge and discharge in rapid succession as in a floating battery, or whether it be completely charged and dis-

charged over the entire range of its capacity. It is also somewhat affected by changes in temperature and density of the electrolyte, but these, however, only in so far as they affect the battery voltage.

In a comparison of these two methods of control it is readily apparent that neither one is exact or accurate because of the uncertainty of battery operation, but it must be said that while in the first controller mentioned, this inaccuracy may cause a complete failure in the operation of the device, for the voltage of the battery may never rise to that assumed value even though the battery is being overcharged, or on the other hand, it may rise to the assumed value before completion of charge, this is not so in the case of the second controller, for the probable error in adjustment may be easily compensated for by assuming the battery efficiency a trifle low and allowing a slight overcharge to occur. The control, however, is absolute and positive.

As far as the mechanical design and operation of the two devices are concerned, it may be said that they are both simple and reliable. It might seem as if a wattmeter were too delicate an instrument for this service, but it is to be noted that there are on the market at present, wattmeters of the mercury type which are of especially robust construction and which have given satisfactory service on electric railway cars.

In regard to the economic value of some such a protective device, attention should be called to the facts that no advantage comes from the power put into a battery after it has reached the fully charged condition, but that all such power is wasted, and that the depreciation of a storage battery in axle service is from 30 per cent. to 80 per cent. annually, depending upon the error of adjustment of the regulator. These facts are generally lost sight of by railroad electricians, who are satisfied if the battery is fully charged when it is needed, and who are content to include this high battery depreciation factor in that of the equipment as a whole, and consider this the price which they must pay for electric lighting. By the proper operation of a controlling device as described above, this battery depreciation could be reduced to 15 per cent. or 20 per cent. annually,

thus effecting a saving which would in one year pay for such a device many times over, besides which, considerable saving of power would be effected.

Such a protective device would also render the operation of the axle equipment more reliable and satisfactory, for the regulator could then be set very high without fear of overcharging the battery and this would provide a speedy recovery of the battery in case it had become exhausted while in the station. In fact, it may be said that on many miscellaneous cars where it is impossible to determine the proper setting of the regulator, the use of some such a protective device is substantially essential to the continued successful operation of the equipment.

CHAPTER V

STORAGE BATTERIES AS APPLIED TO RAILWAY TRAIN LIGHTING

The storage battery has a very important function in the operation of electric lighting equipment on railway trains when acting either as an auxiliary to steam or axle driven generators or as the sole source of power as in straight storage equipments and devices. The storage battery is an expensive and delicate part of such an equipment and the cells require careful attention in order to secure satisfactory operation and to prevent rapid deterioration of the plates.

General Nature of the Storage Cell

The active constituents of a fully charged cell of the lead—lead type consist of peroxide of lead at the positive plates, spongy lead at the negative plates, and the electrolyte (a solution of sulphuric acid in water). During the discharge of the cell, the action is to convert both sets of plates, or electrodes as they are frequently called, into a soluble form of lead sulphate. During discharge the acid combines with the active portions of both plates forming this lead sulphate, which action changes the specific gravity of the electrolyte by removing a portion of the acid. During charging process these actions are reversed; the sulphate on the negative plate is reduced to spongy metallic lead, and that on the positive plate is oxidized to peroxide of lead.

It is to be noted that the sulphate of lead formed during the discharge of a cell is entirely different in its behavior from the white, hard, insoluble form which makes its appearance when a

cell is carelessly managed and to which reference is hereinafter made.

The *electrolyte* is dilute sulphuric acid and may be prepared by diluting a suitable quantity of sulphuric acid with pure water. It is essential that both acid and water be free from impurities. Some impurities such as platinum, iron, copper, and many other metals even in minute quantities tend to cause self-discharge through local action, and lower the efficiency of the battery. Other impurities such as hydrochloric, nitric, and other acids tend to attack and to corrode the lead frame work which supports the active materials. It is, therefore, ordinarily recommended that all acid be purchased from the manufacturer of the battery. Any material obtained from other sources should be carefully tested before using. The purity of the water used for "flushing" the cells should also be carefully determined.

In this connection it is to be remembered that iron frame work or copper connections are attacked by the acid fumes, forming salts highly injurious to the cell if allowed to get into the electrolyte. All such connections to the frame work should be protected by reliable paint or varnish and should be washed occasionally.

The electrolyte used in storage cells has a specific gravity of about 1.2 and may be prepared by mixing one part by volume of sulphuric acid (1.84 Spec. Grav.) with five parts of water. The acid should be poured into the water, never the water into the acid. The acid must be poured into the water slowly and with caution to avoid a violent boiling and sputtering; this boiling hot acid will cause very painful and dangerous burns. The specific gravity should be determined only when the mixture is fully cooled. The prescriptions given by the manufacturers of storage cells of the proper acid gravity to be used in their cells vary somewhat, and the solution should be finally adjusted to the prescribed value by addition of acid or water.

Flushing Cells.—Due to the decomposition of the electrolyte and ordinary evaporation the water in the electrolyte is constantly depleted and must be replaced by fresh pure water, not

acid. This in ordinary railroad work should be done every two weeks at least and in certain cases of overcharged batteries should receive more frequent attention.

On account of the loss of acid by the spraying which occurs at the end of the process of charging, and absorption of acid by the sediment, a gradual lowering of the acid gravity will occur. When on account of the above causes the acid density at the end of a full charge and at normal temperature has fallen 15 points (.015 in the gravity scale) below that normal value prescribed by the makers it should be brought up by the addition of acid.

Acid should never under any circumstances be added to a cell in which short circuits, high temperature, or partial charge may account for low gravity.

Operation of Batteries

Charging.—The battery should preferably be charged at the normal rate prescribed by the maker. It is important that it should be given the proper amount of charge, and once a week a half hour's overcharge, using the normal current for charging, but excessive overcharging should be avoided as it will not only cause a rapid loss of electrolyte but will boil out the active material from the plates, thus greatly reducing their capacity and life.

The readings of the specific gravity of the electrolyte in one cell, or the voltage readings taken from time to time, may be used in following the charge. The specific gravity method is the more accurate as it is independent of the rate of charge, but in railroad work, due to the inaccessibility of the electrolyte, the less accurate but rough and ready method of voltage readings is relied upon. It must be remembered, however, that these voltage readings depend upon the rate of charging and in themselves are no indication of the state of charge unless the normal charging current is flowing. Open circuit voltage readings cannot be in any way relied on.

The normal rate is usually an eight hour rate, i. e., a rate which will give a complete discharge of the battery in eight hours. Thus for a 240 ampere hour battery the normal charg-

ing or discharging current would be 30 amperes. This rate should not be exceeded during the process of charging except for relatively short periods.

The voltage at the end of the charging process is not fixed, but varies as the battery gets older, due largely to an accumulation of insoluble lead sulphate in the active material. Therefore, a battery cannot be said with certainty to be fully charged when it has reached any definite voltage. This voltage at the end of the charging process may vary in new cells from 2.5 to 2.7 and in older cells may be as low as 2.4 when they are fully charged. However, a cell may be considered as charged when the voltage remains constant at approximately 2.5 volts per cell for a half an hour, with the normal charging current flowing.

Discharge.—The limit of proper discharge is reached when the voltage has fallen to 1.8 per cell with the normal current of discharge flowing. This is 28.8 volts on a 16 cell circuit, 57.6 volts on a 32 cell circuit, 90 volts on a 50 cell circuit, and 97.2 volts on a 54 cell circuit, and the batteries should not be discharged below these points.

The rate of discharge and charge should always be within the limits prescribed by the manufacturer. The cells should be carefully inspected and cared for according to the directions of the manufacturer in order that their life may be reasonably long.

An overcharge of a half an hour at the normal rate once a week is a very good thing for any battery in that it tends to prevent formation of the insoluble white sulphate; but such a continued overcharge as was found in tests of many of the axle equipments, is sure to cause a rapid destruction of both positive and negative plates. This is caused largely by the boiling action of the gases mechanically removing the active material of the plates, which collects as sediment in the bottom of the cells. This sediment is not dust nor cinders nor scale nor useless refuse of dead material but is the very life and capacity of the battery itself, so that the depreciation of the battery is, in one direction at least, expressed by the depth of sediment in the bottom of the jars.

Battery Box.—That the temperature may be moderate during summer months and the air dry, the battery compartment must be ventilated. This is also very essential to remove the explosive mixture of oxygen and hydrogen formed during the process of charging the battery.

The importance of the latter is not generally recognized but may be shown by citing a news article in the *Railway Gazette,* 1900, p. 681, which describes a violent explosion under a dining car, which was caused by the collection of oxygen and hydrogen from the cells, this explosive mixture being ignited by an electric spark on a loose connector. Such an accident might easily riddle the battery box and not only cause the total loss of the battery but might be a source of fright and danger to the traveling public. This can easily be remedied by boring a few small holes in each end of the battery box.

To properly preserve the woodwork, particularly the trays and lead lined wooden tanks and also the whole interior of the battery box, care must be taken to keep these parts well protected with a heavy paint which is not subject to the attack of sulphuric acid, preferably one of an asphaltum base.

Cell Tanks or Jars.—A cell tank or jar of special type must be used to withstand the severe conditions of railway operation. In general there are two types which are suitable: lead lined wooden tanks and hard rubber jars set in wooden trays.

The lead lined tank is more expensive, but is without doubt the more reliable and satisfactory. It consists of a heavy oak box of solid construction lined with sheet lead with joints burned to make them water tight; then, to prevent this lead lining from short circuiting the plates, heavy glass plates are fitted inside this lead lining so as to completely cover it. A lead lined cover is bolted over the top of each compartment.

The rubber jar is much cheaper and of more simple construction. It is simply a hard rubber reinforced jar set in a wooden tray, usually in sets of two as illustrated in Plate XXV. A tight fitting rubber cover is also provided to prevent the slopping of acid. This is hardly as satisfactory a jar as the lead lined tank, as it is often cracked or broken, allowing the electrolyte to leak

out, thus completely crippling the battery. However, in case of a lead lined tank care must be taken to prevent grounds and moisture in the wooden container else electrolysis is apt to eat holes in the lead lining and have the same result as a broken rubber jar.

Hard rubber covers are supplied in connection with hard rubber jars, these fitting more or less tightly to protect the plates from dust but at the same time permitting their easy removal for inspection of the plates.

The relative weights of a pair of cells complete of 240 ampere hour capacity of the same type plates in these two types of jars are roughly 200 lbs. in hard rubber and 300 lbs. in lead lined tanks. The relative costs of the tanks alone are roughly $15 for two hard rubber jars and wooden tray, and $24 for a lead lined double compartment tank.

The *connectors* generally used each consist of a rubber covered flexible copper wire with lead lugs burned on the ends. These lugs of lead should be cast so as to completely protect the copper wire from the acid.

CHAPTER VI

COMPARISON OF THE VARIOUS METHODS OF RAILWAY CAR LIGHTING

As in the operation of a train the first essential is to get the train over the road on time and with safety, so in lighting the train the first essential is to have good light all the time, and to do so without jeopardizing the safety of the travelling public. The question of efficiency of operation of a railway car lighting equipment is not only the ratio of power output to intake, but a vast number of other considerations enter into the problem, till the mere machine efficiency or cost of operation becomes of secondary importance.

In considering all the various methods of electric lighting a railway car from a comparative point of view, it must be said that it is impossible to make a sweeping claim of superiority for any one type of equipment. All the equipments operated have certain advantages and certain disadvantages which render each equipment more or less applicable to certain kinds of service. It may also be said that the success of any of the types of lighting equipment lies largely in the hands of the railway operating department.

There are, however, certain features in the operation of the various types of equipment which should be considered in a comparative way.

The simplest of all the electrical equipments used is undoubtedly the straight storage equipment. This, however, has the disadvantage that it requires expensive charging stations at the terminals, by which the batteries are charged each day. This equipment is not applicable to long runs overland, but is most

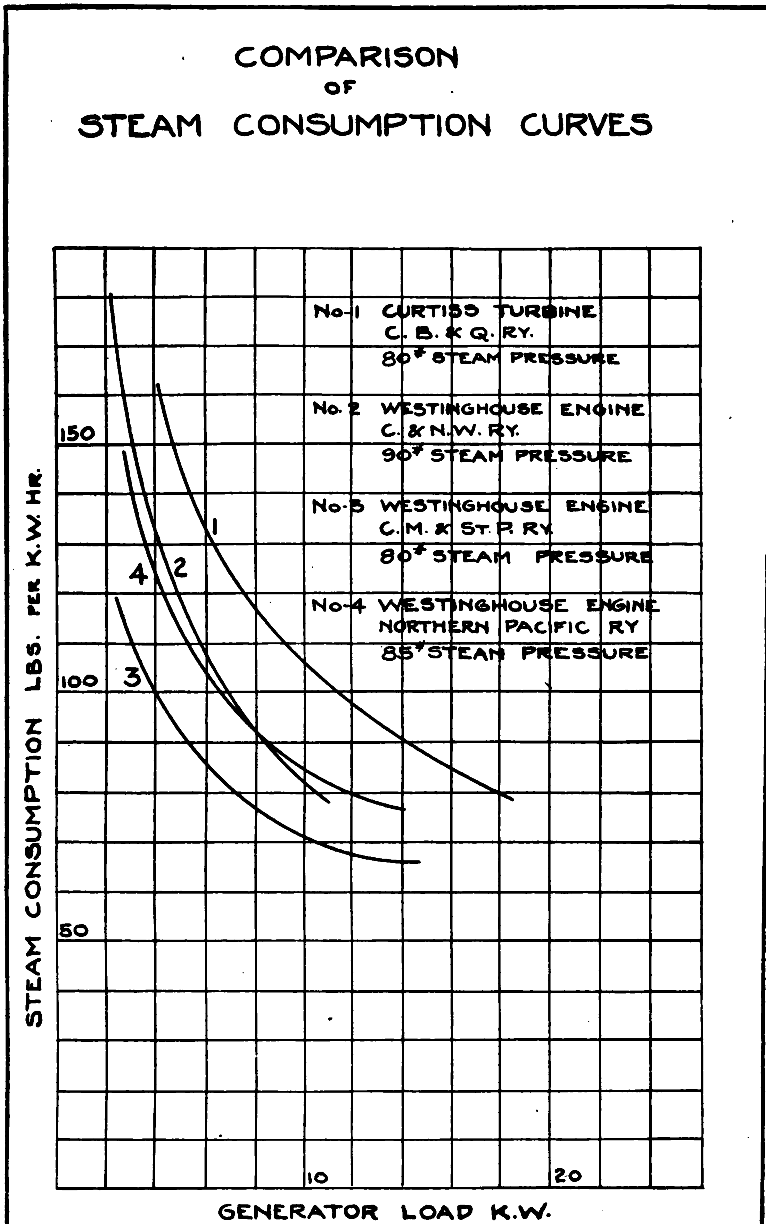

PLATE XLVI.—SHOWING COMPARISON OF STEAM CONSUMPTION OF VARIOUS EQUIPMENTS.

economically operated on short runs where there is heavy traffic and a large number of cars are equipped.

The steam-driven generators are undoubtedly next in the order of simplicity. They, however, have a disadvantage in that they require an attendant. The C., M. & St. P. Ry. and C. & N. W. Ry. have largely overcome this objection by educating their baggagemen to operate the engine sets in addition to their regular duties. Another disadvantage of the system is that the train must be operated as a unit, and will not permit any car not properly wired to be inserted in the train. It is obvious that this type of equipment is most applicable to trunk line trains having a certain definite run, and especially to the overland trains.

The axle equipments have the disadvantage of complexity and high depreciation, but on the other hand they provide that each car is an independent unit, which makes this method of lighting a flexible one which is applicable to cars on miscellaneous runs as well as those in block trains. In fact, it may be said that there are a large number of cars for which this is the only suitable method of lighting by electricity.

The proper operation of axle equipments, however, is such an intricate one that any railroad deciding to enter the field of axle lighting should place a man at the head of that department who has a clear conception of all the theoretical considerations underlying the operation of these equipments and at the same time has a good practical knowledge of storage battery operation. Then that railroad may feel safe in the expenditure of money for such equipment and have every reason to expect a satisfactory and economical return in the method of lighting its cars by electricity. Where a railroad buys a few axle equipments, however, and places them in operation on its cars as a trial, expecting them to care for themselves to a large extent, such an experiment is sure to result in failure and dissatisfaction and a misconception of the real merits of the equipments.

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Wray
Investigation of methods of railway train lighting